UTILIZING GIS AND REMOTE SENSING TO

DETERMINE SHEEP GRAZING

PATTERNS FOR BEST PRACTICES IN

LAND MANAGEMENT PROTOCOLS

by

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Table of Contents

List of Tables

List of Figures

Abstract

Sustainable ranching refers to the practice of evaluating livestock quantities that natural grasses and ecosystems are capable of supporting, with minimal long-term impacts on the environment. Defining optimal and sustainable stocking rates can be a complex problem for land managers striving to implement the practice of sustainable ranching of sheep.

I used a combination of Geographic Information Systems (GIS) with Remote Sensing (RS) to analyze environmental variables and track movement patterns of sheep and tested it at the Lava Lake Livestock and Landscape Ranch. A GIS model utilizing remotely sensed imagery was built to identify areas capable for grazing by sheep across the study area. Tracking Analyst and Time Slider, which are GIS based time analysis tools, utilized point data collected from Global Positioning System (GPS) collars to visualize the rate at which sheep are traveling.

Results show an estimated 85% of the study area is found capable for grazing with the primary eliminating factors being steeper terrain in the north and lack of water in the south. Results also outline two contrasting sheep patterns: a slower travel rate in autumn within the northern regions; a faster travel rate during spring in the more southern regions of the study area. An improvement in achieving even distribution of grazing, offering more resources such as water, and planning rest breaks of intensely used areas can be incorporated in future management plans. A continuation of the project would benefit from a closer look at vegetation specifically plant species type in the various terrains and a biomass study as well as factors affecting vegetation such as precipitation.

1. Introduction and Literature Review

1.1 Sustainable Rangeland Management

Sustainable agriculture defined is to reserve nonrenewable resources, implement natural ecosystem cycles, increase environmental quality, maintain fiscal livelihood of operations, contribute to society, and the lifestyle of farmers (Gold, 1994). Sustainable rangeland management across grassland landscapes has received increased attention over the last 20-30 years (Aagesen 2000; Holecheck *et al*.,1989; Jasmer & Holecheck,1984) creating an awareness to implement appropriate stocking rates for capable landscapes at both private and governmental levels (Krausman *et al*., 2009; Vincent, 2007). In Garret Hardin's *The Tragedy of the Commons* he describes how an unmanaged resource, not without limits, will be left to depletion because those consuming it act in the best interest of themselves and not in the interest of all mankind or society, therefore, it is important to manage resources unsolvable through technology alone by governmental regulations (1968). Sustainable grazing practices work to develop lower impact protocols in rangeland management to reduce desertification and maintain healthy riparian habitats. Such protocols can include: introducing rest breaks (by restricting sheep from overused areas for a period of time to allow the land to regenerate vegetation), reducing overuse of riparian areas, and setting grazing capacity and stocking rates at conservative levels.

Desertification and a loss in riparian habitat are two examples of what can result when unsustainable land management allows for grazing at high levels. It is in the recognition of these issues that sustainability has taken its place among conversations within the land management profession. A study conducted in Argentine, Patagonia by

Aagesen (2000) determined that the European's introduction of sheep ranching, about 100 years ago, created a shift from Patagonia's traditionally lush landscape to an increase in erosion levels and desertification overtime. Land management initially allowed for sheep to graze without any quantity or time restrictions leading to the permanent alteration of Patagonia's natural ecosystem as the grazing rate was too high compared to the natural recovery rate of the vegetation.

The grassland and fauna of riparian habitats impact a variety of species living in and alongside rivers and streams (Armour *et al* 1994; Glimp & Swanson, 1994; Sarr, 2002). Livestock grazing can reduce streamside vegetation and widen channels, which is harmful to the ecosystem (Armour *et al* 1994; Sarr, 2002). Sustainable protocols by the US Department of the Interior (1978) state the necessity of maintaining riparian areas by ensuring that an appropriate level of vegetation exits along the stream bank and sustainable land management practices follow suit to minimize overgrazing in riparian areas.

Sustainable grazing capacities and conservative stocking rates have a goal of minimizing negative impacts on grassland landscapes by setting the appropriate number of sheep to the amount of usable vegetation. Grazing capacity considers the estimated number of animals a landscape can maintain within a given timeframe (Holecheck, 1989; Namken & Stuth, 1997), while stocking rate is calculated by the total amount of usable vegetation divided by how much vegetation a herd of sheep will need to sustain itself (Bizuwerk *et al*, 2005; Holecheck, 1989). Both parameters can be costly and time consuming for land mangers to determine. The traditional way of calculating both grazing capacity and stocking rate is by setting animal unit months (AUM) which is the amount of vegetation a grazing animal needs to sustain itself for one month. Land managers establish AUM's by taking a percentage of an animal's body weight to determine how many pounds of dried vegetation it will consume in one month (Alberta Agriculture and Food, 2007). A primary sustainable grazing protocol denotes the use of conservative stocking rates, i.e. determining the number of AUM's a landscape can sustain and then allowing a portion of that number to be taken as the Bureau of Land Management (BLM) explained in their Final Environmental Impact Statement written in relation to a project for proposing revisions to grazing regulations on public lands. (2004). Rangeland managed to accommodate stocking rates suitable for the grazing capacity is one way of implementing a sustainable agriculture based practice.

Landscape management is difficult due to the necessary analysis of multiple variables over vast areas. The containment of these important variables is made easier through the incorporation of geospatial technology, thus creating a more manageable environment for analysis. Technological advances within the field of Geographic Information Sciences (GIS), Remote Sensing (RS), and Global Positioning Systems (GPS) assist with sustainable rangeland management by looking at grazing patterns and variables in the landscape (Namken & Stuth, 1997; Sampson & Delgiudice, 2006).

GIS provides an environment where pertinent variables can be analyzed on a smaller more manageable scale. Bolstad defines GIS as necessary because it can, "identify the source, location, and extent of adverse environmental impacts, and may help us devise practical plans for monitoring, managing, and mitigating environmental damage" (2008, 4). The GIS does this by accessing two primary sources of data (location and attribute information) and stores both in a database which users can ask questions of and refer to in analysis. For example a polygon representing vegetation can be stored within the GIS as an object containing both its location (i.e. x and y coordinates as they appear on the Earth's surface) and attribute information (i.e. the type of vegetation such as grassland). This allows for important questions necessary for basic analysis to be asked such as: Do sheep eat the plant species that are dominant in these areas? And is it in a location accessible by sheep? If the answer to both is yes then this area is considered capable of being grazed by sheep and in return tells a land manager area to look more closely at for suitability of grazing, which addresses locations more susceptible to adverse impacts such as riparian habitat.

Remote sensing and the use of satellite and aerial imagery allow for feasible acquisition and analysis of spatial data across large areas due to the wide scan collection process and temporal repetition in contrast to field data collection (Marsett *et al*., 2006). A study in the Ulster Valley (Platcher & Hampicke, 2010) emphasizes the effectiveness in utilizing RS to gather spatial data across grazing landscapes. The study used aerial photos, taken from an aircraft, to identify areas across the valley showing signs of impact by animal grazing. An area was imaged once a month for four consecutive months to detect changes in vegetation through time. The results were summarized by land classification in three categories: "affected by vegetation grazing, affected by trampling [a process where hooves of animals destroy vegetation as they migrate] or not affected or effects not recognizable on aerial photographs," (Platcher & Hampicke, 2010, 73) Aerial photography allowed for a four month completion of data where if the exact same data had been collected at the field level it could have taken a year or longer. Remote sensing expedites the acquisition of information important for landscape analysis, making it an efficient resource in sustainable land management protocols.

Global positioning system technology allows for the tracking of animal movement through GPS collars which provides a more precise method to locate and manage live stock such as sheep. Viewing GPS locations over time show patterns depicting how the live stock are moving and the potential intensity at which they are grazing, therefore enabling land managers to identify areas where the animals are staying too long in one location. One such study utilized this technology to analyze the movement of cattle in predicting behavior, the amount of pasture used, and performance. Conclusions found a 95% accuracy of the GPS locations collected which provided accurate analysis for where the cattle were grazing, areas of dispersed movement, and areas of stagnation. Further analysis of GPS points showed an over use of cattle grazing in certain areas (i.e. shaded, close to water) during periods with higher temperatures (Turner et al, 2000).

1.2 Grazing Behavior of Sheep

Interactions between sheep and a foraging landscape can be sustainable when managed appropriately, because the biological relationship between sheep and grasses can be a symbiotic one where both species benefit from one another. Studies have been conducted examining livestock grazing as a potential benefit to creating ideal habitat for certain native bird species and enhancing biodiversity in semi arid landscapes by creating heterogeneity across the landscape as opposed to homogeneity (Derner et al, 2009;

Fuhlendorf & Engle, 2001; Toombs et al, 2010) Livestock introduce heterogeneity by creating different heights in vegetation at various locations creating a variety in habitat type, which has been shown to increase numbers of certain bird species (i.e. Mountain Plover, Baird's Sparrow, Chestnut-collared Longspur) to the area (Fuhlendorf & Engle, 2001) Sheep grazing has also been proposed as a potential tool in habitat management for wildlife, however this takes considerable awareness in the rangeland ecology to determine where, if at all, this could be beneficial because it could be at the cost of another species' habitat (Mosley, 1994).

Grasses are the primary food source for open free ranged sheep therefore, when the health of the grassland suffers so does the health of the sheep. Healthy levels of vegetative land cover in semi-arid landscapes are often determined by measuring biological soil crusts (BSC) (Muscha & Hild, 2006). Studying soil components identifies erosion level and water retention, which are factors contributing to the health of vegetation. Often where there are areas of dense native plant species there are healthy soil levels (i.e. minimal erosion occurring, nutrient rich) therefore; measuring soil correlates with the measurement of vegetation health. Livestock grazing has been known to impact both BSC and soil composition (Muscha & Hild, 2006). There needs to be a balance in the relationship between vegetation and the grazing of sheep for both species to coexist in a healthy and sustainable manner (Glimp & Swanson, 1994). The resources available for land managers to understand both grazing behavior and landscape variables are what maintain this balance.

Grazing refers not only to the consumption of natural foliage, but to any interaction a sheep has on the landscape such as, trampling or diaspore spread, i.e. release of fecal matter containing seedlings of various plant species, (Platcher & Hampicke, 2010). Predicting grazing behaviors can aid in answering questions such as: What sheep are choosing to consume? How intensely are they grazing across the landscape? And what, if any, necessary actions can land managers take to ensure a sustainable ecology exists. Research conducted globally on grazing behaviors from sheep suggests they graze on low land areas (a slope percentage of less than 60), within 2 miles of water, and with an adequate amount of forage (Holechek *et al.*, 1989). Areas meeting this criterion are considered capable for grazing, which is the first step in determining conservative stocking rates by calculating available vegetation of these areas alone. A model conducted by a group of ecologists examined the behavior of grazing by a variety of large herbivores and found a combination of abiotic, biotic, and spatial memory to be causative to the overall grazing patterns developed (Bailey *et al*., 1996). Certain abiotic factors (i.e. slope gradient and distance to water) and biotic factors (i.e. forage availability and type) can create restraints within the overall areas animals choose to graze which can be amplified through spatial memory of these areas by the animal creating overuse and fragmentation of use across the landscape.

1.3 GIS Techniques in Determining Pertinent Land Management Criteria

Environmental management has been a long-standing test bed for the implementation of GIS use as an analytical tool (Goodchild, 2003). A GIS provides an environment where collected information and data can be used in a spatial framework to predict the behavior of animals over several periods of time. Models designed to mimic real world applications, in a controlled environment, allow manageable analysis of data tied to spatial locations resulting in a better understanding of the landscape than field observations alone (Duvall, 2010; Goodchild, 2003; Gough & Rushton, 2000).

Using GIS to analyze grazing capability at a landscape scale is not a new concept. A GIS was used to assist in the development of suitable areas for sheep grazing across the Awash River Basin, located in Ethiopia, as an attempt to identify how efficiently land managers were utilizing the land (Bizuwerk *et al*., 2005). The study used Digital Elevation Models (DEM) to find slope values for the study area as well as water data layers to show areas within a close proximity to water within a GIS. Areas were given weighted values based on erosion levels, average rainfall, distance from water, and slope gradient then analyzed to determine overall suitability. Results concluded that 33% of the Basin was found suitable for grazing however a large portion of suitable area was being used for agriculture crop production. Conclusions determined either a reduction in crop production or moving crops to other locations so as to allow for optimization of suitable areas for grazing reducing grazing pressure in overused areas (Bizuwerk *et al*., 2005).

Another study utilizing GIS to depict rangelands suitable for sheep grazing was conducted in the semi-arid landscapes of Iran (Amiri, 2009). Utilizing rangeland to graze sheep is a monetary and culturally entwined process for Iranians, therefore the study identified areas suitable for such use in order to design grazing management plans in a way sustainable to the land itself. Slope gradients, highly erosive areas, and areas within close proximity to water were all used to generate an output of suitable grazing areas classified into three categories moderately suitable, marginally suitable, and unsuitable. Using the GIS to perform the analysis was said to have offered more accuracy and suppleness in determining the overall rangeland suitability (Amiri, 2009).

The United States Department of Agriculture's Natural Resources Conservation Service also utilized a GIS to design a two part analysis of landscapes used for grazing (Namken & Stuth, 1997). The first part involved creating a grazing pressure model which utilized an algorithm to adjust total grazing capacity for unsuitable slope gradients, distances too far from water, and areas containing high brush densities. The second part used the model to identify appropriate locations for additional water sites (areas suitable for grazing but too far away from a water source) and treatment sites (areas of excessive woody brush in need of reduction treatment to increase desirable forage). The end result was an effective tool for land managers to determine what limitations were causing areas to receive intense grazing and how to minimize this where possible by opening up other limited use areas (Namken & Stuth, 1997).

1.4 Remote Sensing Techniques in Determining Pertinent Land Management Criteria

Remote sensing has been used extensively over the years as a resource in land management with the premise being the use of high-resolution satellite imagery to identify areas where "greenness," i.e. vegetation, occurs (Homer *et al*, 2004; Jiang *et al*, 2006; Knight *et al*, 2006). One satellite known well for its use in vegetation classification is the LANDSAT 7 Enhanced Thematic Mapper (ETM) + (Homer *et al*, 2004). As defined on the National Aeronautics and Space Administration's (NASA) Introductory LANDSAT Tutorial website (http://zulu.ssc.nasa.gov/mrsid/tutorial/Landsat%20Tutorial-V1.html) LANDSAT 7 is the most recent of a series of satellites launched (with one unsuccessful launch for LANDSAT 6) for the purpose of observing Earth. It is equipped with a high end scanner called the ETM + which uses 8 bands each reflecting different wavelengths of light. The Landscape toolbox website explains how the red band (band number 3 on LANDSAT 7 ETM+) and the near infrared band (band number 4 on LANDSAT 7 ETM+) are important in detecting vegetation, because photosynthesis in healthy vegetation absorbs red light and reflects near infrared light where the opposite is true of unhealthy vegetation and non-vegetation reflects light more uniformly (TNC & USDA, 2008). Normalized Difference Vegetation Index (NDVI) is a well known index used to outline vegetation (Jiang *et al*, 2006). NDVI is calculated by subtracting the red bands from the near infrared and dividing this number by the sum of the red bands to the near infrared (Jiang *et al*, 2006):

$$NDVI = (NIR-R)/(NIR+R)$$

The NDVI index is beneficial when used to determine land cover type across landscapes by classifying the landscape into categories based on the vegetation type within an area. For example an area within a pasture may have a number of trees, shrubs, and grasses, however if the grasses make up the majority of the total area the pasture would be given a grassland land cover type. A study conducted for an estuary system in North Carolina and Virginia successfully used NDVI to produce a land cover analysis specifying areas of vegetation type and non-vegetation (Knight et al, 2006). A survey of land managers in the southwest reported a desire in land managers to have timely and reliable vegetation land cover maps to aid in deciding appropriate protocols (Marsett et al, 2006). Land cover that is rapidly derived from NDVI is useful for inclusion into land management protocols because it gives managers the distribution of vegetation in a timely fashion without having to rely on outdated data.

2. Land Management Resource Project

2.1 Project Study Area

The Lava Lake study area is located in south central Idaho neighboring the town of Hailey and The Craters of the Moon National Monument (Figure 2.1 Lava Lake Boundaries and Location). The Lava Lake Land and Livestock (Lava Lake) organization supports conservation of the Pioneers-Craters landscape by managing both private and public (i.e. U.S. Forest Service, Bureau of Land Management) land. One of Lava Lake's conservation efforts is establishing protocols for sustainable sheep grazing across the landscape. Land managers for Lava Lake have worked to develop protocols consistent with conservation based practices for sheep ranching (Bradley & O'Sullivan, 2011). These include, but are not limited to, reducing grazing within riparian habitat (Scheintaub & O'Sullivan, 2009) introducing rest breaks into grazing, and incorporating outcomes from scientific analysis into land management decisions.

Lava Lake was founded in 1999 where a collaboration of multiple sheep and cattle ranches where combined. In 2001 management decisions moved to just the ranching of sheep where an estimated 7,000 ewes graze across allotments (Bradley & O'Sullivan, 2011). Vegetative land cover consists of sagebrush, bunchgrasses, forbs, and shrubland in lower elevations with primarily conifers in higher elevations (Bradley & O'Sullivan, 2011). The climate consists of higher temperatures with minimal precipitation in the summer and lower temperatures with a majority of precipitation occurring in the winter (Bradley & O'Sullivan, 2011).

2.2 Land Management Protocols

Lava Lake's protocols are comparable to land management by other organizations within the business of grazing sheep at sustainable rates and, therefore, will be used to define land management protocols at an organizational level. These protocols comply with federally mandated land management regulations coming from acts managing the use of grazing livestock on public lands and are: the Taylor Grazing Act of June 28, 1934; the Federal Land Policy and Management Act of 1976; the Public Rangelands Improvement Act of 1978 (U.S. Department of Interior, 2004). The Code of Federal Regulations (CFR) established by the United States Department of the Interior incorporates laws in accordance with these three acts offering a uniform reference for what federally mandated protocols are (1978). Lava Lake and these protocols share a common objective to maintain and encourage the sustainability of natural rangeland ecosystems while allowing livestock to graze in a healthy manner.

This project offers a resource for supporting the implementation of these protocols by identifying informational criteria both from the landscape and the behavior of the sheep. Land managers guide the overall grazing process and therefore, to a certain degree, have the ability to control it in a sustainable way by following protocols to the best of their ability. Criteria such as the rate at which sheep are grazing, capable grazing areas, and determinable landscape factors such as slope and water availability assist in meeting protocols such as limiting overuse, striving for an even allocation of use and thus providing adequate rest for vegetation to grow by pointing out areas meeting defined protocols and areas for improvement. In Table 2.1 (Sustainable land management protocols) are summarized Lava Lake protocols, how they relate to federally mandated protocols, and what land management criteria addresses whether or not these protocols are being met.

2.3 Project Objectives

In an effort to support appropriate management of livestock grazing a customized GIS model is used to illustrate grazing patterns for decision making of sustainable stocking rates. Potential grazing patterns are identified by specifying areas likely to be grazed, determining where grazing is occurring and at what rate. Land managers can use this model as a means for spotlighting areas at risk from overgrazing and implement the derived information in their land resources management practice.

Table 2.1. Sustainable land management protocols: Lava Lake protocols as they apply to federal regulations and supportive land management criteria helpful in assisting with protocols.

Lava Lake Protocols	Code of Federal Regulations 4180.2 Standards and guidelines for grazing administration	Land Management Criterion to assist with meeting protocols
"Vary timing and intensity of use for a given area from year to year."	"C (1): Maintaining or promoting adequate amounts of vegetative ground cover, including standing plant material and litter, to support infiltration, maintain soil moisture storage, and stabilize soils"	Identify any areas of overuse for long periods of time.*
"Aim for even distribution use across the largest possible area of capable terrain."	"C (10): Maintaining or promoting the physical and biological conditions to sustain native populations and communities"	Identify areas capable for grazing and then determine sheep rate of travel across these areas to determine stagnation or even distribution.*

Table 2.1, Continued

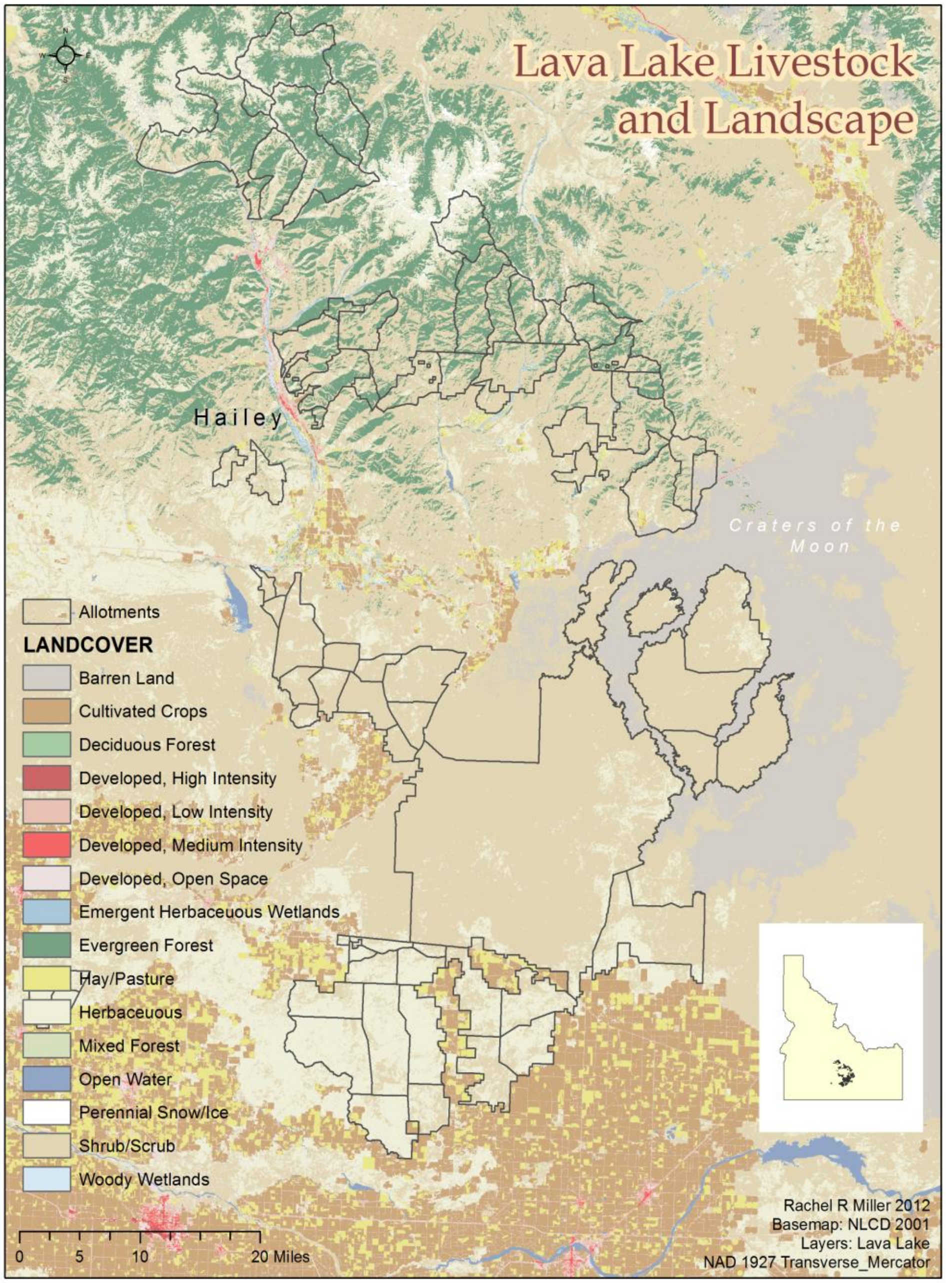
Lava Lake Protocols	Code of Federal Regulations 4180.2 Standards and guidelines for grazing administration	Land Management Criterion to assist with meeting protocols
"Avoidance or altered grazing of riparian areas known to be in poor condition, including many riparian monitoring sites."	"C (3): Maintaining, improving or restoring riparian-wetland functions including energy dissipation, sediment capture, groundwater recharge, and stream bank stability"	Identify conditions of each wetland area across the study area to manage grazing accordingly
"Institute regular patterns of rest, with rest one in three years wherever possible."	**"F** 2(xi): Periods of rest from disturbance or livestock use during times of critical plant growth or re-growth are provided when needed to achieve healthy, properly functioning conditions (The timing and duration of use periods shall be determined by the authorized officer.)"	Identify critical times of plant re-growth for specific plant species across the study area. Identify areas of concentrated use by sheep and work to manage grazing such that these areas receive adequate rest breaks.*
"Stock at conservative levels that anticipate/assume continued patterns of drought and below average precipitation. "	"F (2) (xv): Grazing on designated ephemeral (annual and perennial) rangeland is allowed to occur only if reliable estimates of production have been made, an identified level of annual growth or residue to remain on site at the end of the grazing season has been established, and adverse effects on perennial species are avoided."	Identify conservative stocking rates by 1st deciding areas capable for grazing* and 2nd deciphering within these areas how much grazing capacity exists.

Source: Data for Lava Lake from Tess O'Sullivan, e-mail message to author, March 12, 2012.
Source: Data for Code of Federal Regulations from U.S. Department of the Interior. (July 5, 1978). Electronic Code of Federal Regulations. Title 43: Public Lands: Interior, 4100-4180 Grazing Administration-Exclusive of Alaska.
*Criterion established through analysis of this thesis

GIS based tools used in this project identify heavily grazed and unused areas offering assistance when establishing stocking rates. A capability analysis specifying grazing areas based on known grazing behavior of sheep was automated using Esri's ArcGIS model builder. Derived capable areas will reflect areas within a 2 mile distance from water, at a slope percentage lower than 60, and exclude non-vegetative land cover. Capability outputs are not claiming areas suitable for grazing as suitability is an extension of capability. Land managers will be able to look at areas probable for grazing across the allotment based on capability outputs and from these areas determine whether or not they are suitable for grazing in conjunction with further studies. The "Sheep Grazing Patterns" model, designed for this project, generates areas probable for grazing allowing land managers to look at each area individually and apply their professional knowledge more directly. Sheep movement patterns are identified using two resources within the Esri ArcGIS software, the "Tracking Analyst extension" and the "Time Slider." Through both processes, GIS is able to assist conservation land managers in their goal of sustainable land use across the landscape.

The land management resource project shows potential areas of overuse across the Lava Lake study area using a combination of capability analysis (Ogle & Brazee, 2009) that will show the capable areas a sheep is likely to graze (Capable Sheep Grazing Model) and a time analysis to show probability of how intensely sheep are grazing by identifying areas of use for extended periods of time. The integrated use of NDVI from LANDSAT 7 TM+ assisted the Capable Sheep Grazing model by identifying areas where vegetation exists within the study area. Together they define a more accurate and complete project able to identify prospective grazing patterns then if either were to stand alone. The result is a useful tool for land managers striving for sustainable ranching.

Figure 2.1. Lava Lake Location and Boundaries in South Central Idaho between the town of Hailey and Craters of the Moon National Monument.



3. Acquired and Processed Data

3.1 Lava Lake Data

Datasets created by Lava Lake (see Table 3.1) were made available for this project. Lava Lake has incorporated GIS into their practices over the years, acquiring appropriately formatted data which is privately owned and not made publicly available. The streams layer was derived from the public Digital Line Graph datasets put out by the United States Geological Survey.

The *Streams* and *Springs Troughs* vector files were both used as water source layers from which specified criteria in sheep grazing behavior were determined for the Capable Sheep Grazing model.

The *Allotments* vector file was used to establish specified areas where sheep graze across the Lava Lake landscape; the model's output is generated from the perimeters of these allotments.

The *roads* vector file was also used as an additional water source because in areas with little water, watering trucks will drive water to the sheep.

The temporal analysis uses *GPS 2009* and *GPS 2010* point data layers which are two layers consisting of points collected by five Global Positioning System collars worn by Lava Lake sheep from 2009 to 2010. Both years collected points at an average Positional Dilution of Precision (PDOP) value of 3.38 degrees, meaning the accuracy of the point being collected was within an average of 3.38 degrees to the exact location in real time.

Table 3.1. Summary of Lava Lake Data

Name	Date	Source	Format	Origin	Representation
Springs Trough	unknown	Lava Lake	Point	Hydrography layers and coordinates obtained by (GPS)	Natural occurring springs and water troughs placed by Lava Lake across the study area
Streams	2002	Lava Lake	Line	Digital Line Graphs (DLG) from the USGS and data generated from the Sawtooth National Forest Service	Intermittent and perennial streams, lake and pond boundary lines, stream braids and channels, all found across the study area
Allotments	unknown	Lava Lake	Polygon	Unknown	Boundary of all the allotments managed by Lava Lake
Roads	unknown	Lava Lake	Line	Unknown	Access roads where water trucks can drive out to sheep
GPS 2009	2009	Lava Lake	Point	Collected every 4 hours from GPS collars attached to sheep	Locations of where the sheep are grazing for 2009
GPS 2010	2010	Lava Lake	Point	Collected every 4 hours from GPS collars attached to sheep	Locations of where the sheep are grazing for 2010

3.2 National Elevation Datasets

National Elevation Datasets (NED) (Table 3.2 Summary of NED Data) were downloaded from the United States Geological Survey's (USGS) Seamless Data

Warehouse (http://seamless.usgs.gov). A total of four NED's were downloaded in ArcGIS raster GRID format. They were in a 1/3 arc second resolution (approximately 10 meters), the most precise resolution available for the study area. The USGS offers NED's as a resource for acquiring elevation data for the conterminous United States, ((USGS), U.S. Geological Survey, 2009). These datasets were used for the calculation of slope values in order to specify criteria in sheep grazing behavior (see section1.2).

Table 3.2. Summary of NED Data

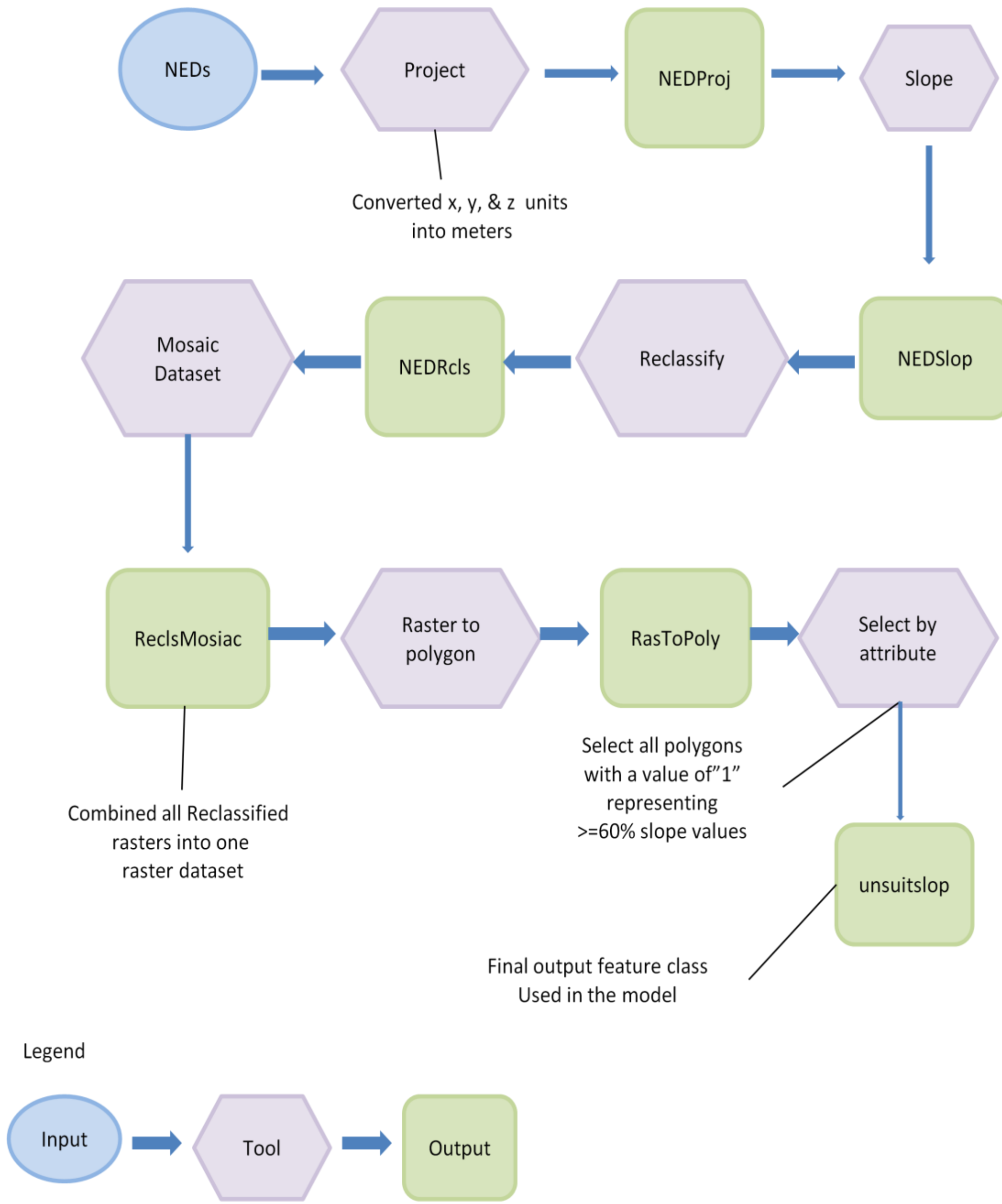
Name	**Date**	**Source**	**Format**	**Origin**	**Representation**
N43w114	2009	USGS	Raster	USGS National elevation dataset (NED)	Elevation levels for the south eastern quadrant of study area
N43w115	2009	USGS	Raster	USGS's National elevation dataset (NED)	Elevation levels for the south western quadrant of study area
N44w114	2009	USGS	Raster	USGS's National elevation dataset (NED)	Elevation levels for the north eastern quadrant of study area
N44w115	2009	USGS	Raster	USGS's National elevation dataset (NED)	Elevation levels for the north western quadrant of study area

Preparation of NEDs

For the NEDs to be used within the model (see Figure 3.1 Preprocessing of NED's) additional preparation needed to take place. Generation and grouping (i.e. reclassification) of accurate slope values were necessary to establish suitable areas of travel for grazing by sheep. The first step in the process was establishing appropriate units of measurement to calculate accurate slope percentage across the landscape which determines the percent rise from each cell within the NED to its neighboring cells. Percent slope is calculated by dividing the rise (the increase in units vertically from one cell to the next) by the run (the increase in units horizontally from one cell to the next) and multiplying this value with 100. The NED's exist in a Geographic Coordinate System using decimal degrees as their units of measure, and follow the guidelines of the 1983 North American Datum ((USGS), U.S. Geological Survey, 2009). An issue with incorrect slope percentage will occur when performing slope analysis using decimal degrees for the horizontal components (x value, y value) and meters for the vertical component (z values). To derive correct slope percentages each NED was projected into the Transverse Mercator projection, placing all the x, y, and z values in the same unit (meters).

The slope percentage dataset was calculated as floating-point and the next step consisted in the conversion from floating-point to a binary integer output grid when performing the reclassification using the **reclassify** tool. The classified slope percentage was then divided in two groups to which new Boolean values were assigned: from 0.000000-59.999999 % slope were given value "0", while all values $\geq$ 60 % slope were given value "1". The lowest slope percentage for "n43w114" is 0.000000 and the highest slope percentage is 348.285553, therefore, while reclassifying this particular NED the range of values were divided as follows: 0.000000-59.999999% are given a value of "0" and 60.000000-348.285553% are given a value of "1" the other three NED's were reclassified in a duplicate fashion.

Figure 3.1. Preprocessing of NED's for use in the model



The final step created a mosaic database in which all NED's could be merged together. Afterward, the raster was converted into a vector polygon format used for analysis within the model. A query was then performed using **select by attribute** to query out all of the polygons with a value of "1." A new feature class was created by exporting the selected polygons and saving them as their own separate feature class named *unsuitslop*. This final feature class was used in the model to eliminate all the areas with slope percentages of 60 or greater and is shown overlaid to the processed percent slope of NED "n43w114" in Figure 3.2.

3.3 National Land Cover Database Imagery

The most recent National Land Cover Database (NLCD) was completed in 2001 by numerous U.S. governing agencies constituting the Multi-Resolution Land Characteristics (MRLC) Consortium. The NLCD (Table 3.7 Summary of NLCD Data) was derived from imagery, encompassing all four seasons, taken by the LANDSAT 7 ETM + satellite (Homer *et al*, 2004). LANDSAT imagery with a nominal 30 meter ground resolution is better suited for this study and the detail required in this investigation as opposed to other satellite imagery with smaller scale ground resolution. NDVI index values were calculated to identify different vegetation types as well as non-vegetation types.

Preparation of NLCD Imagery

The NLCD was used to extract non-vegetative or vegetative areas incapable for grazing (i.e. cropland) from the study area. The data was preprocessed before being integrated to the model as shown in Figure 3.3 (Preprocessing of NLCD data). Land cover types deemed unqualified were the following: Barren Land, Cultivated Crops,

Figure 3.2. Unsuitable slope feature class overlaid to the NED "n43w114" slope values.

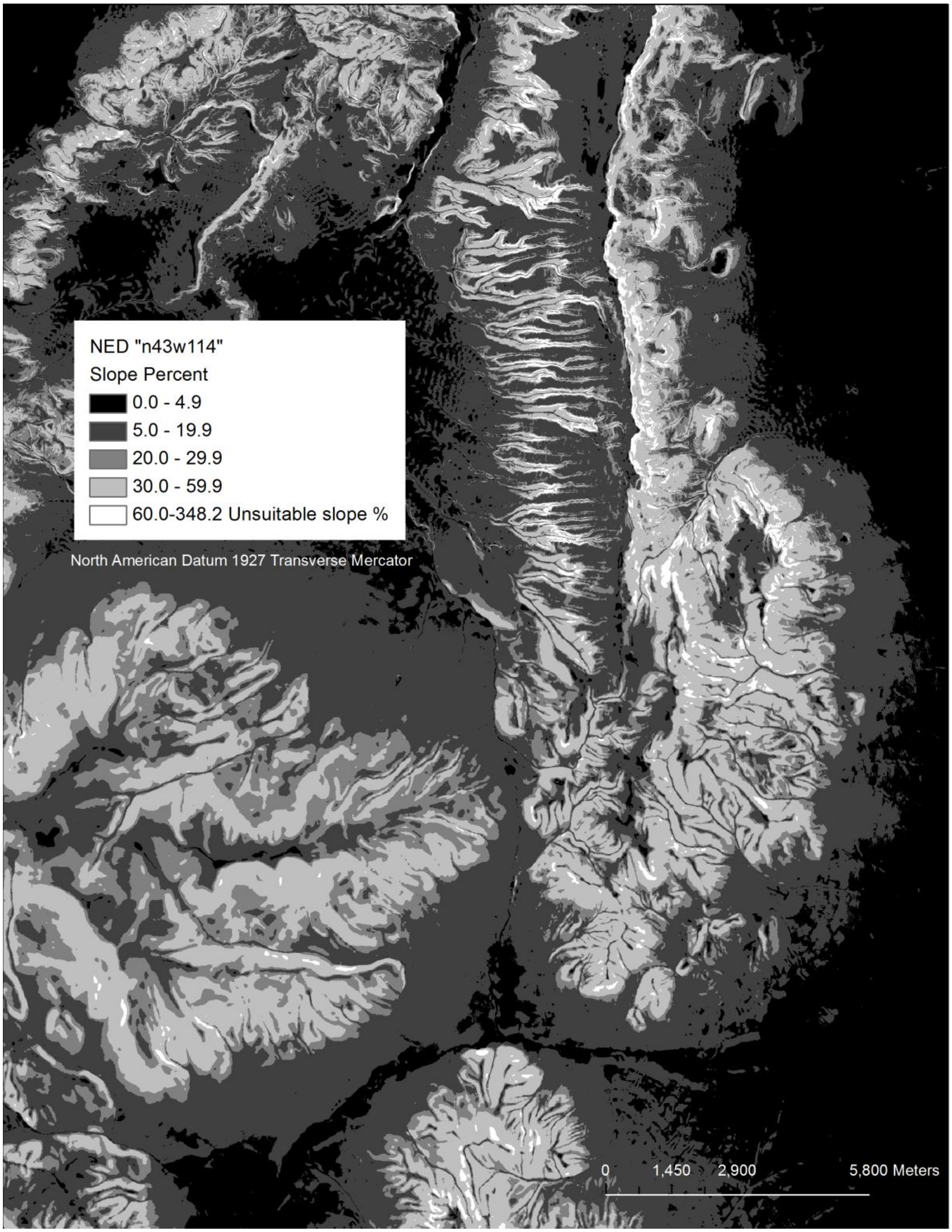
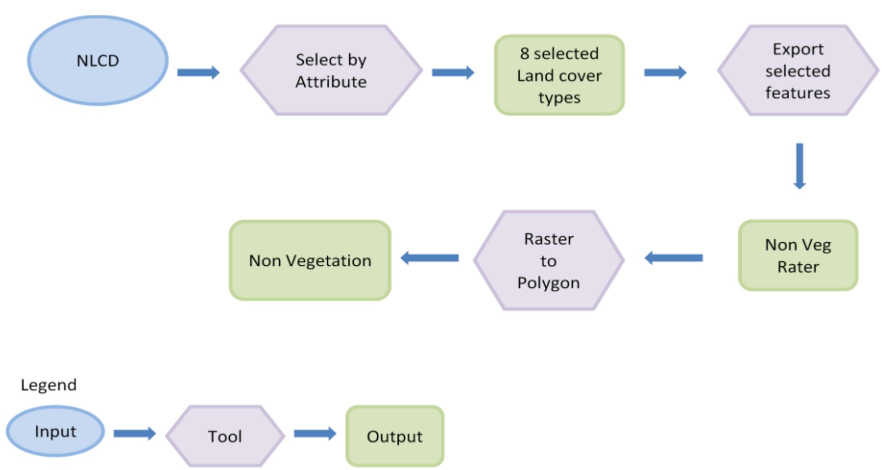


Table 3.6. Summary of NLCD Data

Name	Date	Source	Format	Origin	Representation
NLCD	2001	MRLC	Raster	LANDSAT 7 TM+ Imagery	16 categories of land cover type • Barren Land • Cultivated Crops • Deciduous Forest • Developed, High intensity • Developed, Low Intensity • Developed, Medium Intensity • Developed, Open Space • Emergent Herbaceous Wetland • Evergreen Forest • Hay/Pasture • Herbaceous • Mixed Forest • Open Water • Perennial Snow/Ice • Shrub/Scrub • Woody Wetlands

Developed High, Medium, and Low Intensity, Developed Open Space, Open Water, and Perennial Snow/Ice.

Figure 3.3. Preprocessing of NLCD data



3.4 Construction of the Geodatabase

Spatial database systems store geographic locations represented as points, lines, or polygons while also incorporating pertinent information tied to such locations. They are unique in comparison to standard database systems because of their ability to manage geometries providing a framework for the organizing, querying, and analyzing of spatial data (Yeung & Hall, 2007). Within the Esri ArcMap software spatial databases are called a geodatabase as explained on Esri's ArcMap desktop resource center website (2012). One entitled *LL_Model* (Lava Lake Model) is created for the project to incorporate organization, ease of model transferring, and is necessary through preliminary steps in the project figure 3.4 (LL Model Geodatabase and contents within Esri's Arc Catalog) shows the organization of data and the Capable sheep grazing model contained in the Geodatabase.

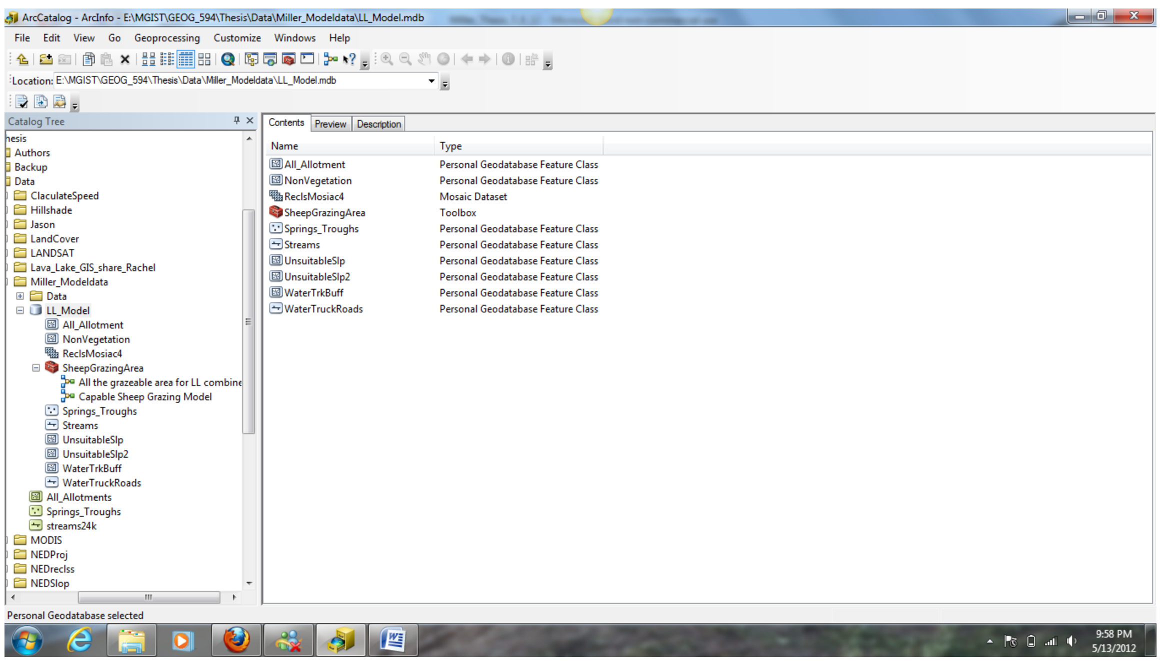
All thematic layer feature classes were uploaded into *LL_Model* providing one organized location for all data. A requirement for adding data to a geodatabase is all data layers must be projected in the same geographic coordinate system as the geodatabase. The *LL_Model* projection is the North American Datum 1927 Transverse Mercator, chosen based on appropriateness for the study area and also defining the majority of existing acquired data.

A benefit to having all the data in one centralized location is the ability to transfer this data among land managers. Lava Lake works closely together with a variety of land managers overseeing separate, yet intertwined, departments within the organization as a whole. Accessing both the Capable Sheep Grazing Model and the data within this project is readily available for any pertinent individual through one location: the geodatabase.

Sharing the project with multiple land managers is also made easier by having all inputs, processes, and outputs stored in one container allowing the entire project to be transferred through transferring the geodatabase.

Certain processes within ArcMap require the formation of a geodatabase before they can be implemented. Two of these processes were necessary for this project they are: creating the mosaic raster dataset from NED's (see section 3.2) and creation of the Capable Sheep Grazing model (see section 4.2). Creating *LL_Model* provides a storage platform for the administering and housing of the raster dataset and the model.

Figure 3.4. LL Model Geodatabase and contents within Esri's Arc Catalog



4. Methodology

4.1 Establishing Land Management Criteria

The land management resource project identifies areas capable for sheep grazing and areas sheep could be grazing more intensely. A capability analysis and a time analysis are conducted using Esri’s ArcGIS establishing criterion from a suite of datasets within the LLModel Geodatabase. The criterion identified from this analysis will guide land management protocols such as identifying any area of overuse, areas capable of grazing, sheep rate and stagnation, and where to implement rest breaks.

The capability analysis directly addresses protocols of even distribution and setting appropriate stocking rates as the time analysis addresses protocols of even distribution and varying timing and intensity of use. Seeing where capable areas are underutilized offers a way to achieve a more even distribution across the landscape by expanding into these areas. If initial stocking rates are determined using all areas across the landscape (both capable and incapable) they will not be appropriate for the level at which the landscape can sustain itself while being grazed. Eliminating incapable areas from the overall grazing capacity helps to determine accurate AUM’s which in return is used to set conservative stocking rates. The Time Slider mimics any stagnation in movement by sheep pointing out areas of uneven distribution across the landscape as well as identifies areas being used heavily for a period of a month or longer.

4.2 Capable Sheep Grazing Model

A capability analysis specifying grazing patterns based on protocols and known grazing behavior of sheep is automated using Esri's ArcGIS **Model Builder**. Model builder is structured such that manual processes within ArcGIS are automated through a flow chart organization. Automation offers ease of use, and organization offers a visual layout of methods followed in the project. The construction consists of inputs, tools, and outputs with additional variables and parameters to guide the overall flow (Allen, 2011). One reason for utilizing model builder was allowance of multiple users, including non GIS professionals, to map capable grazing areas. Another was to create a manageable sharing of processes within Lava Lake.

There are two main parts to the capability criteria within the capable sheep grazing model. The first, producing areas of land within a 2 mile distance to water and the second showing areas of land with less than 60% slope. In Figure 4.1 (Capable Sheep Grazing Model) is shown the model and its layout in Model builder, showing all inputs, tools, and outputs. It is automated to run on a user specified allotment (i.e. boundary of land ownership across the Lava Lake Landscape) within which it produces areas where sheep are capable of grazing.

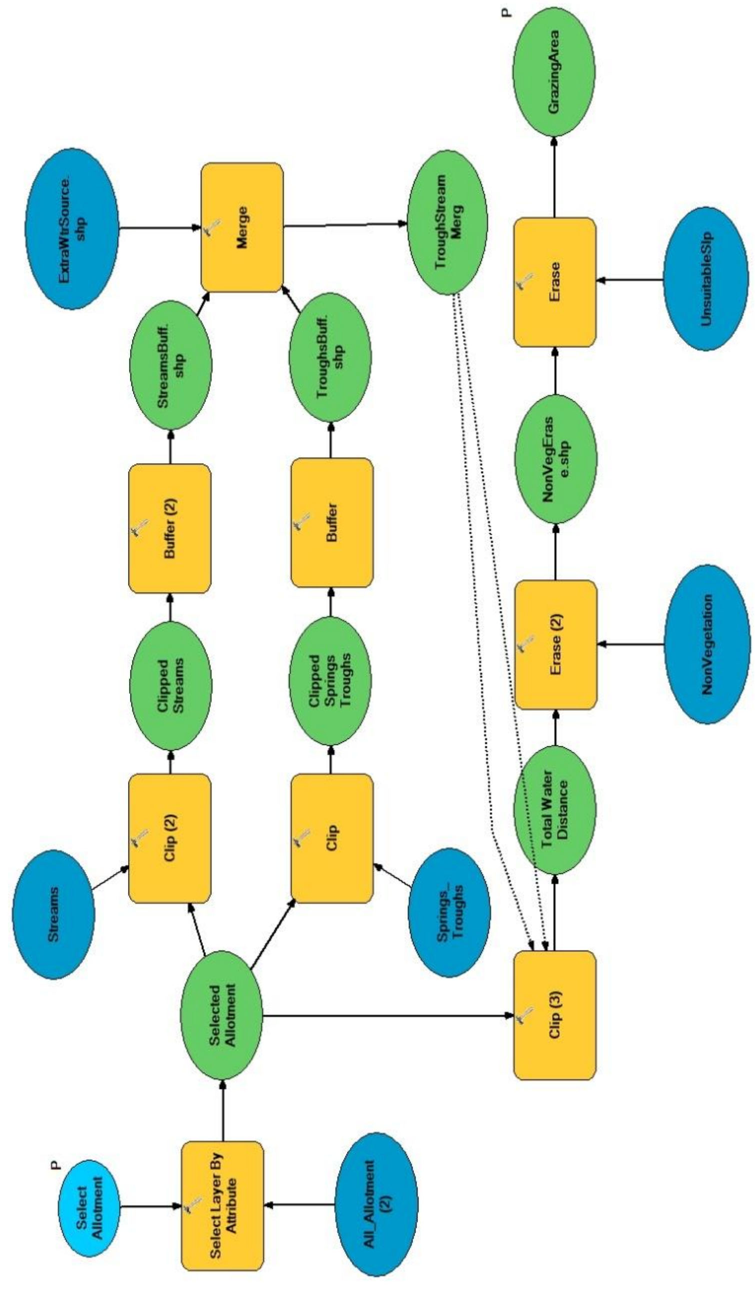
The first step is set up with a user-defined parameter allowing a sequel expression to be created to define a specified allotment. Then, both the *Troughs/Springs* and *Streams* feature classes are clipped to the selected allotment using the **clip** tool. A precondition is applied to both clip tools to allow the selection of the allotment to take place before the clips are run. Next, both *Trough/Springs* and *Streams* feature classes are buffered at a 2 miles distance using the **buffer** tool. The buffer outputs are then merged together, in conjunction with a roads buffer layer, using the **merge** tool and clipped back to the selected allotment. A precondition is set so the merging of the two buffer classes will occur before they are clipped to the initially selected allotment. All tools are added to the capable sheep grazing model by dragging and dropping them from the search menu in ArcMap. Preconditions are set via the tool properties dialog box, and parameters are established using the model builder context menu.

The second process uses the new feature class *unsuitslop*, generated from the NED's, and *nonvegetation*, generated from the NLCD, to erase them from the output of the first process (i.e. Total Water Distance) using the **erase** tool. A parameter is attached to the final output, so the user is prompted to specify the name of the final polygon feature. This allows the user to choose an appropriate name applicable to the allotment for which the Capable Sheep Grazing model is being run, as well as allows for running the model on multiple allotments without overwriting final outputs. It is also indicated to "Add to display" the final output, so the polygon is added to the map upon completion. The final output shows areas within a 2 mile distance from water, with slope percentage lower than 60 and vegetation coverage consisting of grassland, pasture, and herbaceous.

4.3 Sheep Temporal Patterns

There are many patterns of sheep grazing that are unseen when viewing points on a map. Animating movement as it occurs throughout time lets users see patterns in paths and rate providing information helpful to grazing management. The ability of Esri's **Tracking Analyst** and **Time Slider** tools to provide such visual analysis made them appropriate for use within this thesis.

Figure 4.1. Capable Sheep Grazing Model.



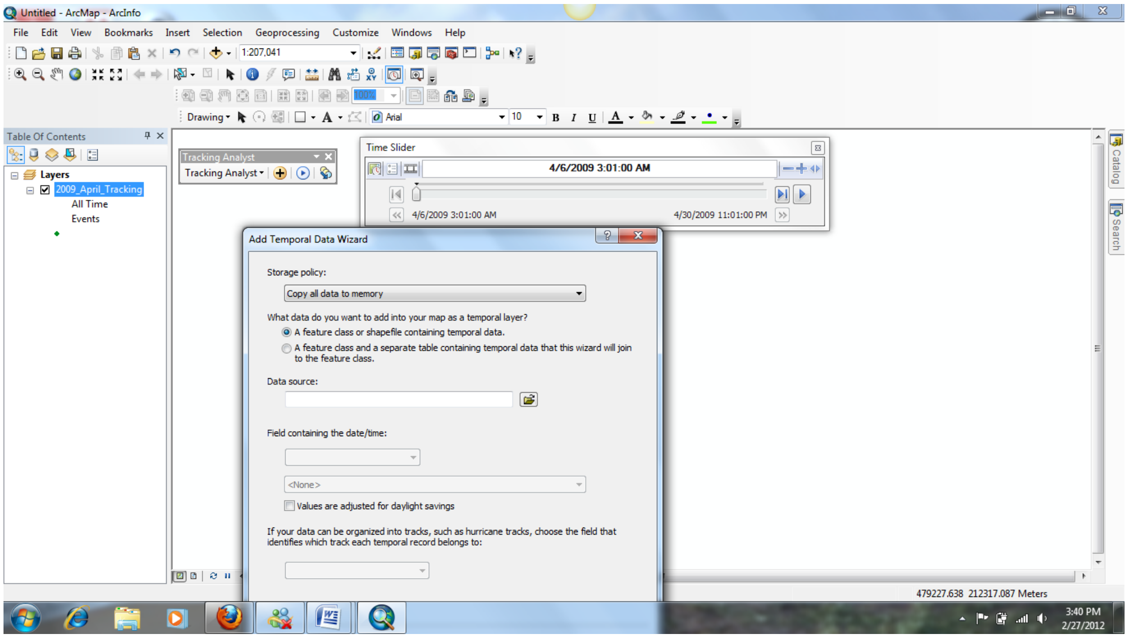
Tracking Analyst is a toolbox containing viable time management tools, permitting recorded time elements in data to be manipulated. Date and time attributes of a feature class are used to specify time properties producing a time sensitive layer as an output. The time layer is then used in conjunction with the Time Slider tool which plays each feature in sequential order. The end result is an animation of features as they move across the landscape through time.

Certain steps are necessary to undertake time analysis. The first is enabling both tools for use within the GIS. Tracking Analyst is an extension and was accessed by adding the Tracking Analyst toolbar to ArcMap. Time Slider is an application programming interface available on the main toolbar, within ArcMap, where it remains unavailable for use until a time layer is created and added to the map (Figure 4.2 Time Slider, Tracking Analyst, and the Temporal Data Wizard, shows all of them open within ArcMap).

The second process is the establishment of time properties for each GPS point layer. The **Concatenate Date and Time** tool (available within the Tracking Analyst toolbox) was used to join the “Date” and “Time”, attributes in the 2009 and 2010 GPS point feature classes, giving each feature a unique time stamp for the specified day recorded. The temporal data wizard (made available through the Tracking Analyst toolbar) was then used to identify time attribute fields, time and date formats, and unique id fields all properties pertinent to the creation of a time layer. Tracking Analyst was used to generate six time layers; one for the spring, summer, and autumn seasons within each year.

After each time layer was created and added to the map, the Time Slider is available for use. The Time Slider is used to manipulate the extent and rate at which each feature’s unique time stamp is moved through.

Figure 4.2. Time Slider, Tracking Analyst, and the Temporal Data Wizard enabled and running within ArcMap



The extent was set to one month when visualizing the movement of sheep during different seasons (Spring: April; Summer: July; Autumn: September), and the extent was set to one year when looking at how the sheep moved throughout the entire grazing period (beginning of April to the beginning of October). The rate in all time analysis was set to move through each features time stamp every second. The extent, (i.e. timeframe) for each session is set in the Time Slider through its properties, and the speed at which the Time Slider moves through each timestamp is set through the time layer's properties. For example, one hour between timestamps could be played every second, one day between timestamps could be played every second and it is dependent on the time scale the user wants to visualize. For the purposes of this analysis the speed is set to move through each timestamp every second.

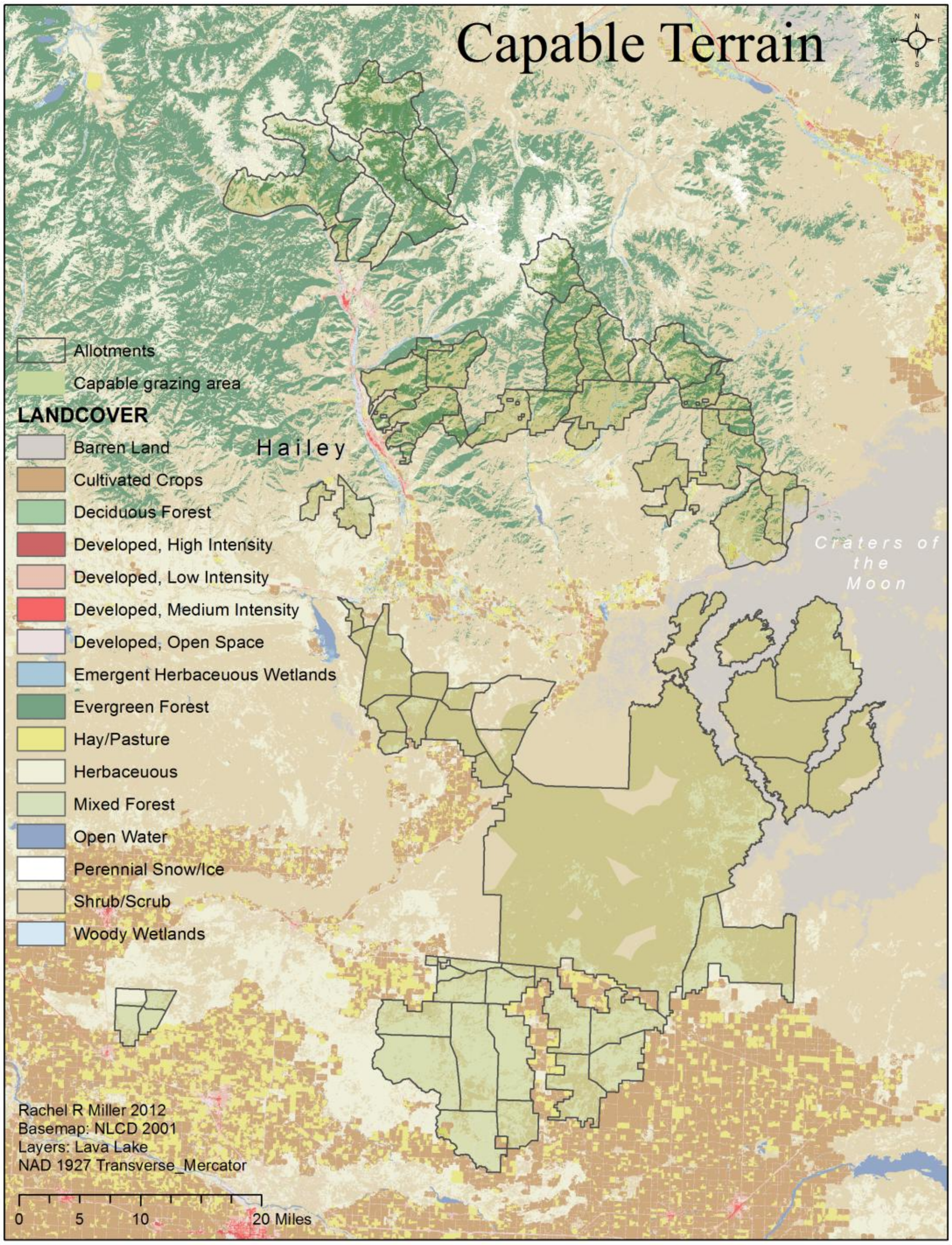
5. Results

5.1 Capability Analysis

The capability analysis shows areas capable of grazing and provides more accurate acreage, when considering stocking rate, then accounting for the total acreage a study area encompasses Figure 5.1 (Capable terrain for the study area). Eliminating unusable areas when calculating total acres is a first step to setting appropriate stocking rates. The outcome offers a better perspective of land available to land managers so they can then look more closely at the suitability of these areas as well as include vegetation estimates across the landscape from only capable areas. For the year 2009 3,829 GPS points out of a total 4,084 points located inside an allotment were found within these capable areas (an accuracy of 94%) and for the year 2010 4,035 points out of 4,146 total points were found within capable areas (an accuracy of 97%). From a total of 900,000 acres in the study area, 763, 044 acres were found to be capable of being grazed by sheep, an estimated 85 percent. In Table 5.1 (Total acreage capable for grazing by allotment) it shows the calculated acreage considered capable of grazing by allotment, and its subsequent percentage based on total acres for that allotment.

A more accurate calculation of acreage deemed capable for grazing is defined based on the Capable Sheep Grazing model's output polygons. The allotments in the southern and central regions of Lava Lake appeared to be prominent with more flat terrain (low slope percentages) and greater areas of vegetation. However, this area also has the least number of water sources available, thus eliminating otherwise viable acreage due to a distance further then 2 miles from water.

Figure 5.1. Capable terrain for the study area



The Timmerman Hills allotments located in the southern region signify these results as shown in Figure 5.2 (Areas capable for grazing in the Timmerman Hills North allotment). The majority of the Timmerman Hills North allotment was found not capable for grazing, where the other surrounding allotments were found highly capable of being grazed (97%-98.5%). Even though there is no steep terrain or non-vegetative areas a good portion of the allotment is at a distance further then 2 miles from water.

The primary factor contributing to the elimination of areas for capability in the Northern allotments is the presence of high slope percentages. These allotments are rich with water supply and have minimal non-vegetative land cover. However, the steep terrain in this region keeps them at smaller percentages than allotments found in the central and southern regions.

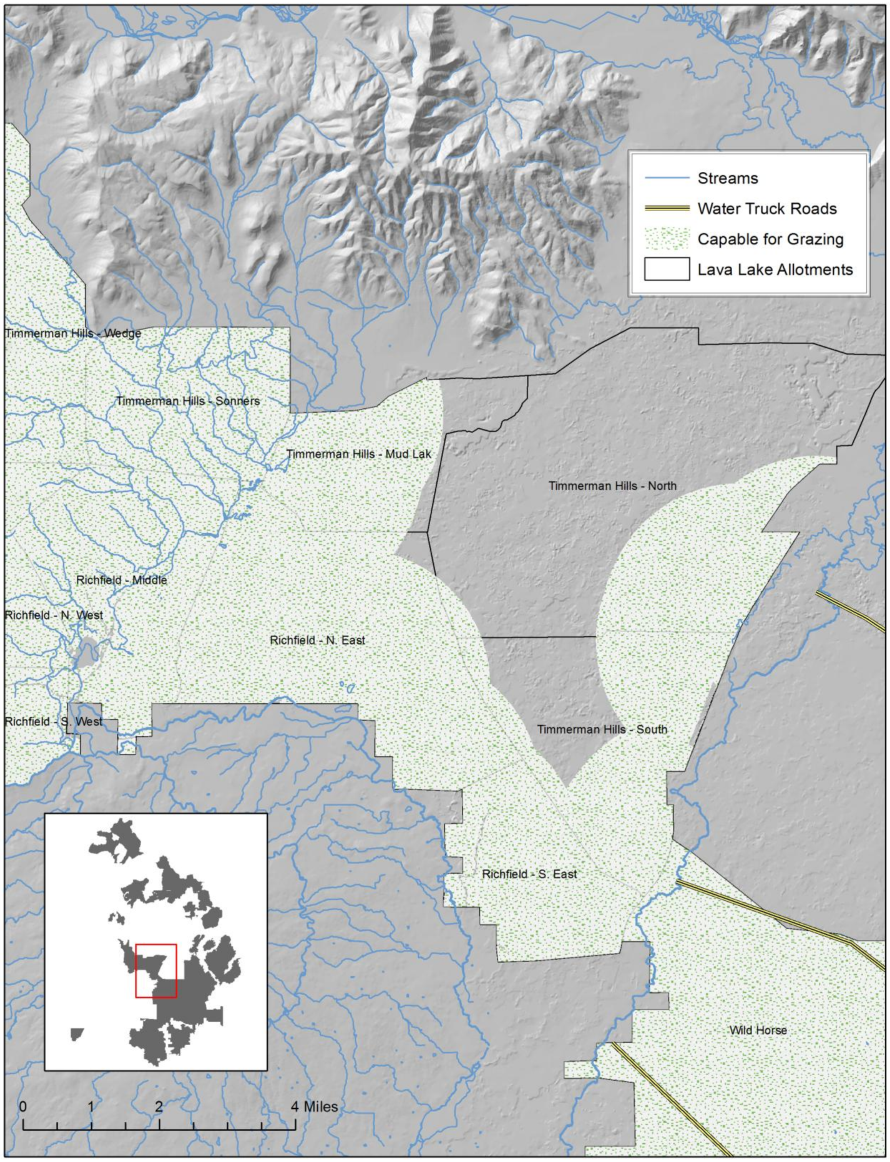
Table 5.1. Total acreage capable for grazing by allotment

Input		Output		Total % Capable of Grazing
Allotment Name	**Acres**	**Allotment Name**	**Acres**	
Balsamroot	3842.501	Balsmrrotgrz	3736.46	97.24
Buckhorn	15022.54	Buckhorngrz	10856.17	72.27
Copper Creek	7735.689	CopCrkgrz	6458.92	83.5
Cottonwood	6312.66	CottWoodgrz	5525.55	87.53
Cove Creek	8921.087	CoveCrkgrz	8225.49	92.2
Crater	4339.437	Cratergrz	2086.15	48.07
Fish Creek S&G	2187.262	FishCrkgrz	1840.66	84.15
Garfield	7303.628	Garfgrz	4680.22	64.08
Hurst Canyon S&G	10853.4	HurstCnygrz	8332.86	76.78
Indian Creek	12632.81	IndCrkgrz	10708.4	84.77
Iron Mine	14164.71	IronMngrz	11843.7	83.61
Kent Canyon	2678.622	KentCyngrz	2665.93	99.53
Kimama	29359.14	Kimamagrz	29124.7	99.2
Laidlaw Park - Middle	31121.25	LaidlawMgrz	30928.9	99.38
Laidlaw Park - North	26734.05	LaidlawNgrz	26617.6	99.56
Laidlaw Park - South	9071.545	LaidlawSgrz	9032.06	99.56
Laidlaw Park - Thumb	19669.98	LaidlawPTgrz	15757.7	80.1
Laidlaw Park-Little Park	7801.078	LaidlawPrklilgrz	6342.7	81.3
Lava Lake	16160.89	LavaLakegrz	13795.7	85.36
Little Wood	6610.808	LilWoodgrz	5794	87.64
Muldoon	18351.95	Muldoongrz	15255.3	83.13
North Fork Big Lost River	21758.86	NrthFrkBLRgrz	16195.1	74.43
North Fork Boulder	34040.6	NrthFrkBldgrz	23150.1	68.01
Park Creek	12236.67	ParkCrkgrz	7221.59	59.02
Pot Creek	10895.28	PotCrkgrz	6631.91	60.87
Quigley	9954.027	Quigleygrz	8373.82	84.12
Richfield - Middle	5123.481	RichFMgrz	4982.95	97.26
Richfield - N. East	7919.617	RichFNEgrz	7725.81	97.55
Richfield - N. West	4684.53	RichFNWgrz	4684.53	100
Richfield - S. East	3343.819	RichFSEgrz	2855.19	85.39
Richfield - S. West	2264.583	RichSWgrz	2233.52	98.63
S. East Fork	1915.04	SEForkgrz	1462.27	76.36
Sheep Creek	8458.178	SheepCrkgrz	8003.35	94.62
Sid Butte - N. East	11317.71	StarLakegrz	10200.7	90.13
Sid Butte - N. West	11715.87	SidButteNEgrz	11074.8	94.53
Sid Butte - S. East	10079.25	SidButteNWgrz	11257.8	111.7
Sid Butte - S. West	11327.17	SidButteSEgrz	9659.92	85.28
Spring Creek	3108.05	SidButteSWgrz	10795.2	347.3

Table 5.1, Continued

Input		Output		Total % Capable of Grazing
Star Lake	10317.32	SpringCrkgrz	2941.11	28.51
Star Lake - Camp 2	18652.88	StarLakeC2grz	18616.6	99.81
Star Lake - Cinder BT	12247.47	StarLakeCBTgrz	11164.9	91.16
Star Lake - Cinder BT E.	7396.429	StarLakeCBTEgrz	7095.45	95.93
Star Lake - E. Bull	1494.44	StarLakeEBgrz	1233.15	82.52
Star Lake - Heifer	477.186	StarLakeHggrz	447.64	93.81
Star Lake - Mallard	5803.559	StarLakeMgrz	5760.86	99.26
Star Lake - Owinza	5713.099	StarLakeOgrz	5579.78	97.67
Star Lake - Sand Blow	1380.42	StarLakeSBgrz	1316.08	95.34
Star Lake - Stage Barn	13871.59	StarLakeStBrngrz	13664.1	98.5
Star Lake - W. Bull	2373.533	StarLakeWBullgrz	2211.75	93.18
Star Lake - Wilson Ridge	18410.84	StarLakeWgrz	18406.2	99.97
Timmerman Hills - Mud Lak	3401.885	TimmHillMLgrz	2695.51	79.24
Timmerman Hills - N	1577.663	TimmHillNgrz	1550.64	98.29
Timmerman Hills - North	13986.89	TimmHillNrthgrz	2813.49	20.12
Timmerman Hills - S	1729.623	TimmHillSgrz	1656.3	95.76
Timmerman Hills - Sonners	3928.299	TimmHillSonngrz	3928.3	100
Timmerman Hills - South	5741.062	TimmHillSthgrz	1678.51	29.24
Timmerman Hills - Wedge	13208.89	TimmHillWedgrz	13162.8	99.65
Trail Creek	24276.61	TrailCrkgrz	14932.7	61.51
Trail Creek S&G	4759.037	TrailCrkSGgrz	4350.73	91.42
Upper Fish Creek	3208.8	UpFishCrkgrz	2393.76	74.6
Upper Rock Creek	5326.183	UpRockCrkgrz	4958.71	93.1
Upper Slaughterhouse	2309.773	UpSlaughtHsgrz	2123.05	91.92
Water Gulch	920.177	WaterGlchgrz	656.98	71.4
Wendell Ct. N. East	2205.211	WendlCtNEgrz	2026.79	91.91
Wendell Ct. N. West	2175.536	WendlCtNWgrz	0	0
Wendell Ct. S. East	2228.649	WendlCtSEgrz	268.67	97.31
Wendell Ct.. S. West	3738.586	WendlCtSWgrz	3683.54	98.53
West Fork	7350.173	WestFrk	7231.18	98.38
Wild Horse	240454	WildHorse	220096.1	91.5
Spring Creek	3108.05	SidButteSWgrz	10795.2	347.3

Figure 5.2. Capable grazing in Timmerman Hills North and surrounding allotments (there are no slope percentage > 60 in the allotment, showing the main eliminating factor is distance to water)



5.2 Time Analysis

The Time Analysis shows that there is a correlation between the time of year and rate at which the sheep are traveling as well as between the various terrains in the different regions of the study area and the rate. Based on these findings land managers can begin to identify patterns in the way their sheep are moving and look at other factors that may be contributing to them. The outcome identifies areas frequented more often by the sheep, which could translate into areas receiving more grazing pressure. Table 5.2 shows the number of GPS points and the number of days per dates by allotment representing the amount of sheep activity in each allotment during the different seasons for the year 2009 and 2010.

The Time Slider animates the overall grazing pattern of sheep monitored by GPS for the years 2009 (5 collared sheep) and 2010 (5 collared sheep) which is as follows: at the beginning of April sheep start in the south central allotments and are herded by horsemen up through the central region, traveling outside study area boundaries with permission in order to arrive at the most northern allotments by about June, and then they are herded back down south ending in the north western and north eastern regions by September staying there until October to early November. Patterns visualized among each year showed sheep traveling faster during the spring and summer season than during the autumn, as shown in Table 5.2 a majority of northern allotments have an increased number of days in conjunction with an increased number of points when compared to the southern allotments translating into a higher amount of use in this region of the study area. In the autumn of both years the sheep appeared to stay more stationary in their movement. Spring appeared to be the season were sheep traveled the fastest as shown in Figure 5.3 (Difference in rate of travel during spring, summer, and autumn) by the point locations from the same GPS collar, one day in April, July and September for the 2009 and the 2010 grazing years. An explanation of the time analysis seen while playing features in the Time Slider is presented in this figure. The points in the two September panels (bottom) are much closer together then those in April and July, showing a condensed area of travel by sheep in September, and a vast area covered in April and July.

Table 5.2 Total number of days sheep graze (as represented by GPS generated points) in each allotment for the 2009 and 2010 grazing year.

Northern Allotments

Name	**Total points for 2009**	**Dates/ # days**	**Total points for 2010**	**Dates/ # days**	**Total capable acreage**
Lava Lake	301	6/1-6/14; 10/9-11/29 (34 days)	90	5/7-6/19 (43 days)	13795.70
Cottonwood	101	6/1-6/26 (25 days)	96	6/8-6/28 (20 days)	5525.55
Crater	12	6/15-6/20 (5 days)	23	6/13-6/23 (10 days)	2086.15
Iron Mine	608	6/28-10/17 (111 days)	284	6/27-9/28 (93 days)	11843.7
Balsamroot	75	5/25-6/5 (11 days)	152	5/22-6/20; 9/4-9/16 (41 days)	3736.46
West Fork	138	5/27-6/30 (34 days)	202	5/26-6/28; 9/7-9/26 (52 days)	7231.18
Upper Fish Creek	109	6/29-9/22 (86 days)	71	7/2-9/26 (87 days)	2393.76
Fish Creek S&G	41	7/31-8/6 (7 days)	125	7/4-8/1; 9/17-9/24 (35 days)	1840.66
Trail Creek S&G	64	7/20-8/5 (16 days)	86	7/6-9/17 (72 days)	4350.73
Hurst Canyon	0	0	181	7/19-9/6 (48 days)	8332.86
Muldoon	151	5/30-7/12; 9/14-9/22 (49 days)	228	5/31-7/25; 9/20-9/30 (66 days)	15255.30
Spring Creek	17	10/8-10/12 (5 days)	0	0	10795.20
Garfield	55	7/31-8/12 (13 days)	115	7/30-8/23 (25 days)	4680.22
Copper Creek	148	6/21-9/14 (85 days)	191	6/17-9/20 (95 days)	6458.92

Table 5.2, Continued

Name	Total points for 2009	Dates/ # days	Total points for 2010	Dates/ # days	Total capable acreage
Little Wood	0	0	75	5/31-6/14 (15 days)	5794.00
Buckhorn	109	6/21-6/24; 8/20-9/14 (30 days)	91	6/19-6/20; 7/4-7/10; 9/1-9/16 (26 days)	10856.17
Pot Creek	0	0	0	0	6631.91
Sheep Creek	142	5/31-6/23 (24 days)	160	6/14-7/11 (38 days)	8003.35
Upper Slaughter House	27	6/24-6/29 (6 days)	24	7/12-7/16 (5 days)	2123.05
Water Gulch	0	0	0	0	656.98
Quigley	73	6/29-7/4; 9/19-10/14 (32 days)	38	7/16-7/22; 9/29-10/2 (11 days)	8373.82
Indian Creek	93	6/17-6/27; 7/9-7/14; 9/16-9/19 (21 days)	56	9/15-9/27 (13 days)	10708.4
Upper Rock Creek	58	5/28-6/7 (10 days)	57	5/31-6/10 (11 days)	4958.71
Kent Canyon	41	6/8-6/16 (9 days)	0	0	2665.93
Trail Creek	43	8/2-8/6; 9/12-9/15 (9 days)	96	7/28-8/5; 9/17-9/25 (18 days)	14932.7
Park Creek	48	8/7-8/11; 9/6-9/12 (12 days)	72	8/6-8/9; 9/7-9/16 (14 days)	7221.59
North Fork Big Lost River	133	8/12-9/5 (24 days)	148	8/11-9/6 (26 days)	16195.10
Name	**Total points for 2009**	**Dates/ # days**	**Total points for 2010**	**Dates/ # days**	**Total capable acreage**
North Fork Boulder	133	6/29-7/31 (33 days)	189	6/13-7/26 (44 days)	23150.10
S. East Fork	0	0	4	9/15-9/17 (3 days)	1462.27
Cove Creek	343	7/1-9/17 (18 days)	342	7/17-9/28 (73 days)	8225.49

Table 5.2, Continued

Southern Allotments

Name	Total points for 2009	Dates/ # days	Total points for 2010	Dates/ # days	Total capable acreage
Laidlaw Park-North	0	0	22	5/15-5/17 (3 days)	26617.60
Laidlaw Park Middle	64	5/9-5/20 (11 days)	48	5/6-5/18 (12 days)	30928.9
Laidlaw Park-South	25	5/5-5/9 (5 days)	13	5/4-5/6 (3 days)	9032.06
Laidlaw Park-Thumb	0	0	0	0	15757.70
Laidlaw Park-Little park	9	5/20-5/21 (2 days)	11	5/18-5/19 (2 days)	6342.70
Kimama	36	4/4-4/17 (13 days)	0	0	29124.7
Wild Horse	631	4/18-5/23 (6 days)	563	4/22-5/17 (25 days)	220096.10
Timmerman Hills-North	41	5/12-5/24 (13 days)	13	5/22-5/24 (3 days)	2813.49
Timmerman Hills-South	28	5/11-5/17 (7 days)	12	5/14-5/22 (9 days)	1678.51
Timmerman Hills-Sonners	19	5/14-5/17 (4 days)	18	5/16-5/18 (3 days)	3928.30
Timmerman Hills-Wedge	30	5/17-5/22 (6 days)	37	5/19-5/25 (7 days)	13162.80
Timmerman Hills-N	16	5/22-5/24 (3 days)	9	5/25-5/26 (2 days)	1550.64
Timmerman Hills-S	0	0	2	5/25 (1 day)	1656.30
Timmerman Hills-Mud Lak	6	5/13 (1 day)	6	5/15 (1 day)	2695.51
Richfield-North West	0	0	0	0	4684.53
Richfield-North East	2	5/12 (1 day)	8	5/20-5/21 (2 days)	7725.81
Richfield-Middle	0	0	0	0	4982.95
Richfield-South West	0	0	0	0	2233.52
Richfield-South East	0	0	17	5/17-5/19 (3 days)	2855.19
Star Lake-Wilson Ridge	1	4/10 (1 day)	34	4/18-4/23 (6 days)	18406.2
Star Lake-Stage Barn	63	4/6-4/17 (12 days)	8	4/22-4/25 (4 days)	13664.1

Table 5.2, Continued

Name	Total points for 2009	Dates/ # days	Total points for 2010	Dates/ # days	Total capable acreage
Star Lake-Mallard	30	4/4-4/10 (7 days)	0	0	5760.86
Star Lake-Owinza	19	4/10-4/19 (10 days)	28	4/18-4/21; 4/25-4/26 (6 days)	5579.78
Star Lake-East Bull	1	4/18 (1 day)	1	4/22 (1 day)	1233.15
All remaining Star Lake	0	0	0	0	43793.53
All Sid Butte	0	0	0	0	52988.42
All Wendell Ct.	0	0	0	0	5979

There is also a correlation between the rate of travel by the sheep and the terrain they are traveling on during different times of the year. While the sheep are grazing in the autumn months (September to the beginning of October) they are located primarily in the north western and north eastern allotments. These allotments are steeper and at higher elevation then those in the south central region, therefore these factors could be contributing to the overall reduction in travel rate.

Through these results it appears that seasonal differences, steep terrain, or a combination of the two factors are contributing to a higher concentration of use in the northern allotments as opposed to the protocol of achieving a more even distribution of use across capable terrain. Comparing the amount of time (number of days) the sheep are grazing to the amount of capable grazing available in each allotment there is a trend of excessive time spent in the northern allotments where there is less capable acreage. For example Figure 5.4 (Amount of time spent grazing) shows an increase number of days spent grazing in allotments that have less capable grazing acreage while sheep are in the north (i.e. Iron and Mine had sheep graze 111 days in 2009 and 93 days in 2010 with only about 12,000 capable acres) and the reverse while grazing in the south (i.e. the Sid Butte allotments combined had no sheep grazing in them for 2009 & 2010 however has an estimated 53,000 capable acres). One could assume these areas are receiving higher levels of grazing pressure. However, further analysis of other primary contributing factors (i.e. vegetation) would need to be conducted in order to test this hypothesis.

Figure 5.3 Difference in rate of travel during spring, summer, and autumn (all shown at a scale of 1:20,000). Small point clusters between the hours of midnight and around 8 in the morning are possible bedding sites. The distance between the daytime points show a faster rate of travel in the Spring and Summer allotments during April and July then in the Autumn allotments during September. This correlates between both 2009 (right panel) and 2010 (left panel).

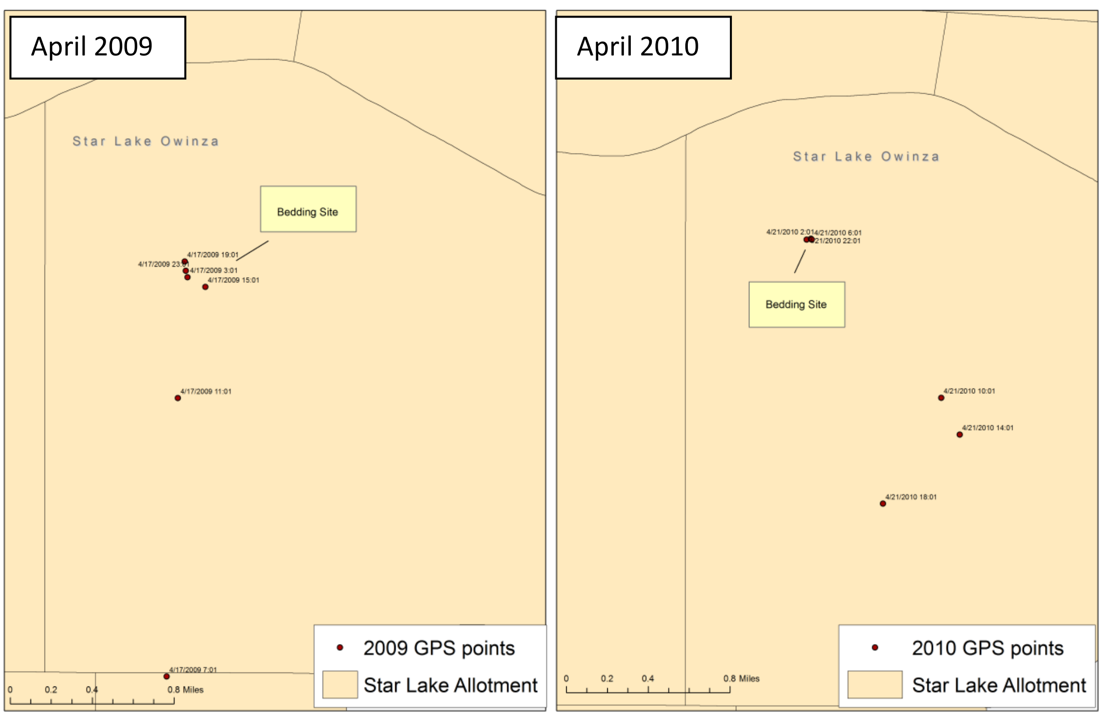


Figure 5.3, Continued

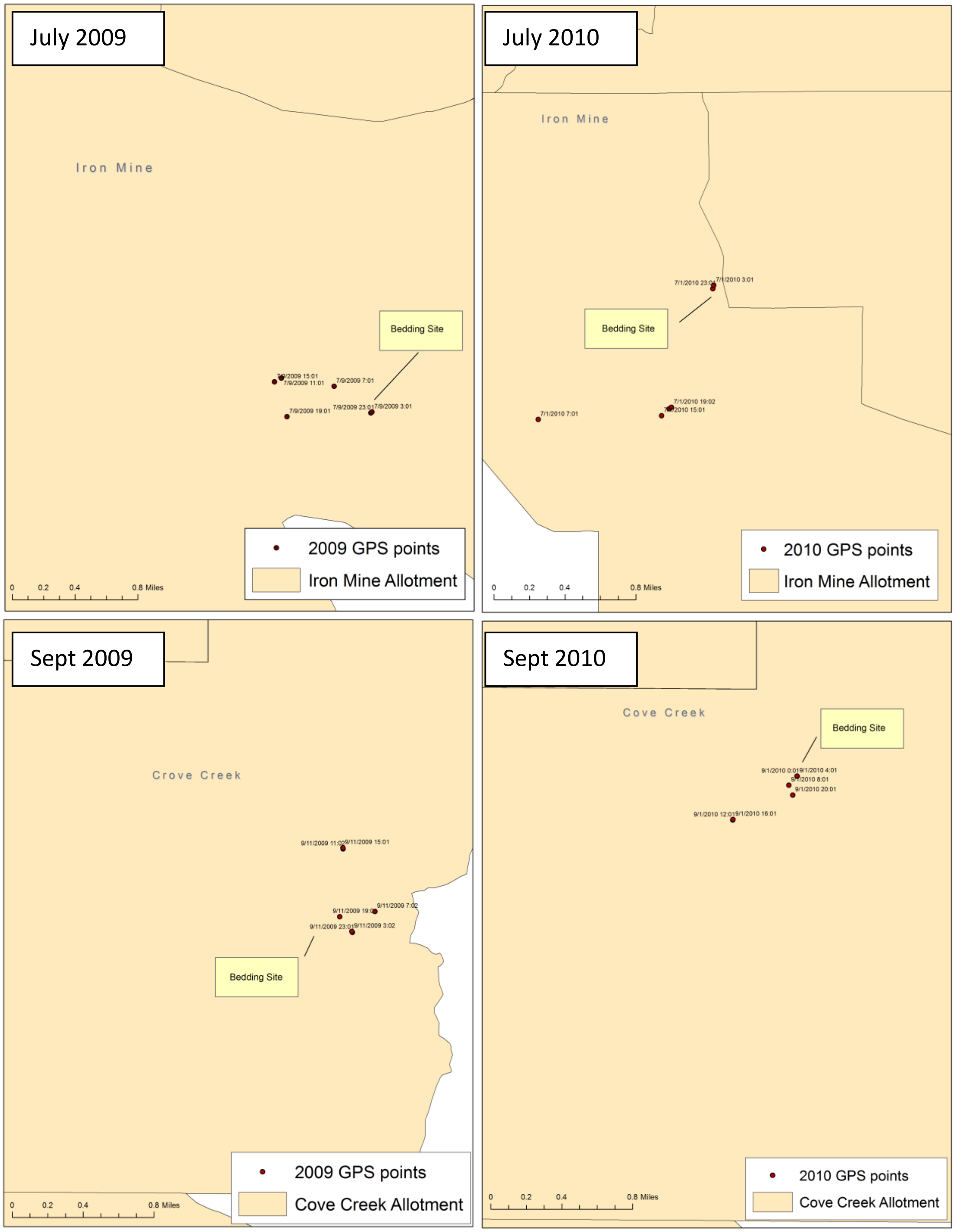
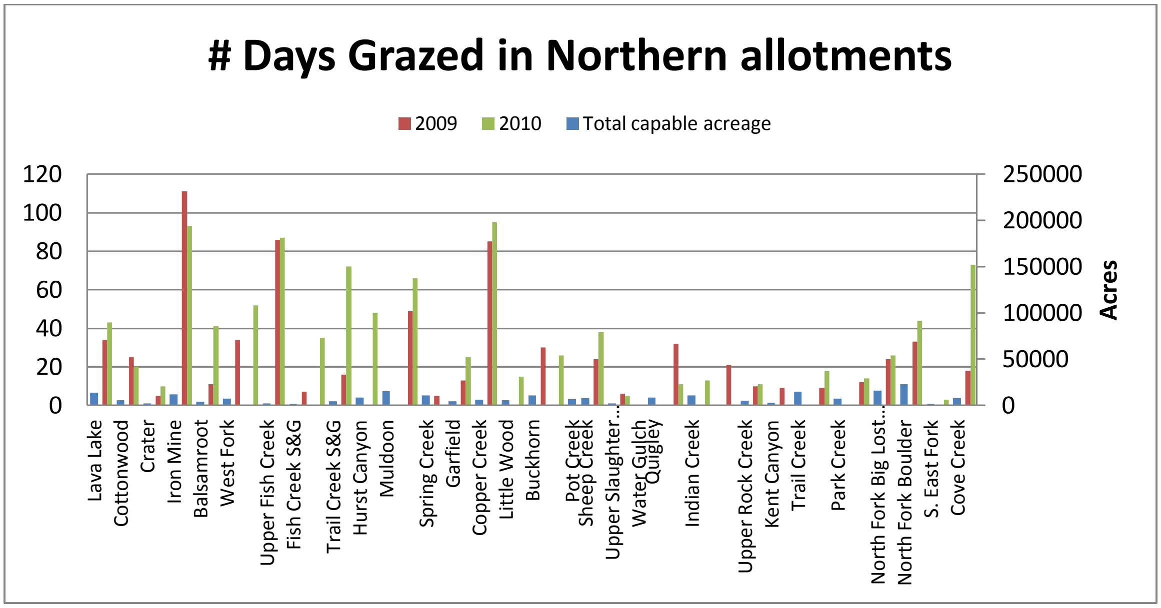
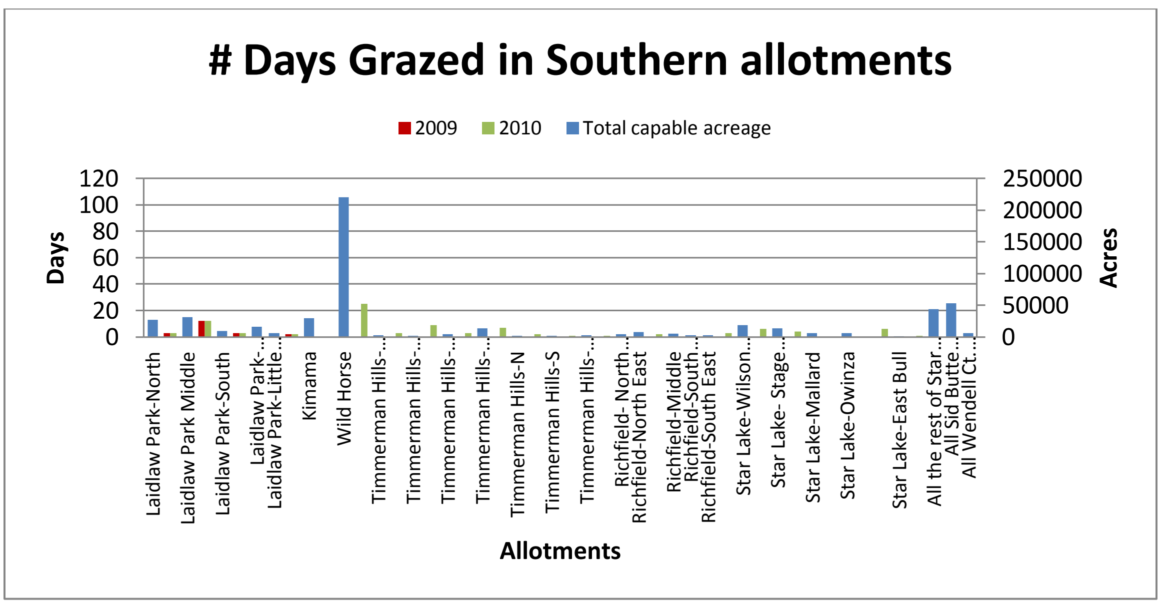


Figure 5.4. Amount of time spent grazing: The number of days spent grazing in each allotment for the 2009 and 2010 grazing year (left axis) compared to the amount of capable grazing acreage available for the allotments (right axis). Maximum values are set to the highets number of days and highest number of capable acreage for the entire study area.





6. Conclusions and Discussion

Sustainable land management is driven by protocols where identification of pertinent land management criterion addresses how well these protocols are being implemented. Resulting criterion determines strengths as well as areas for improvement in addressing whether or not sustainable protocols are being met. The analysis of GIS model outputs in conjunction with the time tools show a more accurate representation of areas where sheep could graze and how they are grazing across the Lava Lake rangeland which in return offers valuable information for areas which may be at risk of overgrazing.

6.1 Capability Analysis and New Criterion

The capability analysis addresses criteria important to the implementation of sustainable land management protocols. In particular it identifies areas capable of grazing that are not being accessed efficiently and therefore prompts to provide respite of overused areas by completing the first step to assign appropriate stocking rates. Given this information, additional land management decisions such as changing grazing routes, opening up incapable areas through introduction of necessary criterion, and identifying the overall grazing area by capable boundaries as opposed to allotments can be made.

The northern allotments show the highest concentration of use, as shown in Figure 6.1 (Dispersion of use as shown through GPS locations for 2009 and 2010), therefore the potential stress induced on the vegetation in these areas identify them as prime candidates for looking at implementing rest breaks, where appropriate, while still viable for the health of the sheep. Within the northern allotments there are areas capable of being grazed that are not heavily used. The outlined distributions could guide the grazing of sheep in a sustainable way by increasing the use of less concentrated areas and reducing the use of stressed and overused areas, therefore allowing for vegetation re-growth and assisting with sustainable management protocols in future years. Areas eliminated due to unsatisfying requirements of distance from water sources could also be utilized if decisions were made to fulfill these requirements where applicable. For example, in the southern allotments the capability analysis showed many areas eliminated because of a distance greater than 2 miles away from water, however if water were to be made available in these areas, through troughs or other such resources, this would make them available for use providing additional means for alleviating stressed areas.

The analysis of the grazing capability of the entire study area showed a vast percentage of the land as useful for grazing confirming that the study area appropriate for the management of sheep. The definition of the capable boundaries maps however offer a more precise method to identify areas that are and will be grazed compared to a generalized map view of the land sheep are grazing that was previously used by land managers. This is the first step in setting conservative stocking rates for the landscape because it eliminates all the area most unlikely to be grazed, therefore when Lava Lake takes the next steps toward establishing how much capacity (i.e. total estimated dry weight vegetation biomass) exists only the capable areas will be taken into consideration defining a more accurate quantification of the overall vegetation available. This estimate will also provide land managers an ideal number of sheep they should allow to graze while still being within sustainable ranching practices by deciphering how much vegetation they have to sustain the optimal number of sheep and then managing numbers below this.

6.2 Time Analysis and Seasonal Patterns

The time analysis shows how patterns begin forming in the way in which the sheep and the landscape are relating to one another. Once these patterns are identified land managers can determine whether or not protocols introducing variety in timing and use of the landscape, from year to year, satisfy an even distribution and sustainable practices. This analysis shows a need for improvement in reaching these protocols by reducing the grazing intensity while sheep are in the northern allotments.

Results from the time analysis show that sheep traveling at slower rates are within areas of greater concentration. This combination could negatively impact the vegetation within these areas causing them to be at greater risk of desertification or loss in habitat. The rate could be slowed due to the steeper terrain in the northern allotments or it could correlate to higher temperatures during the time of year in which sheep graze in these areas. Also, the northern allotments are used by Lava Lake during the majority of the grazing year (4 to 5 out of 7 to 8 months total) identifying areas of overuse for long periods of time. These factors are shown in the analysis as stagnation in movement which is unconstructive to achieving both protocols of variety in timing and use from year to year of an even distribution across the land. Land managers could act based on the results by adding additional shade resources in areas where there is evidence of high temperatures stress during the year, or decide to use different allotments during different seasons in variation from year to year in a hope of encouraging more even use across the landscape.

Figure 6.1 Distribution of use as shown through GPS locations for 2009= 4,544 points total (top panel) and 2010= 4,459 points total (bottom panel).

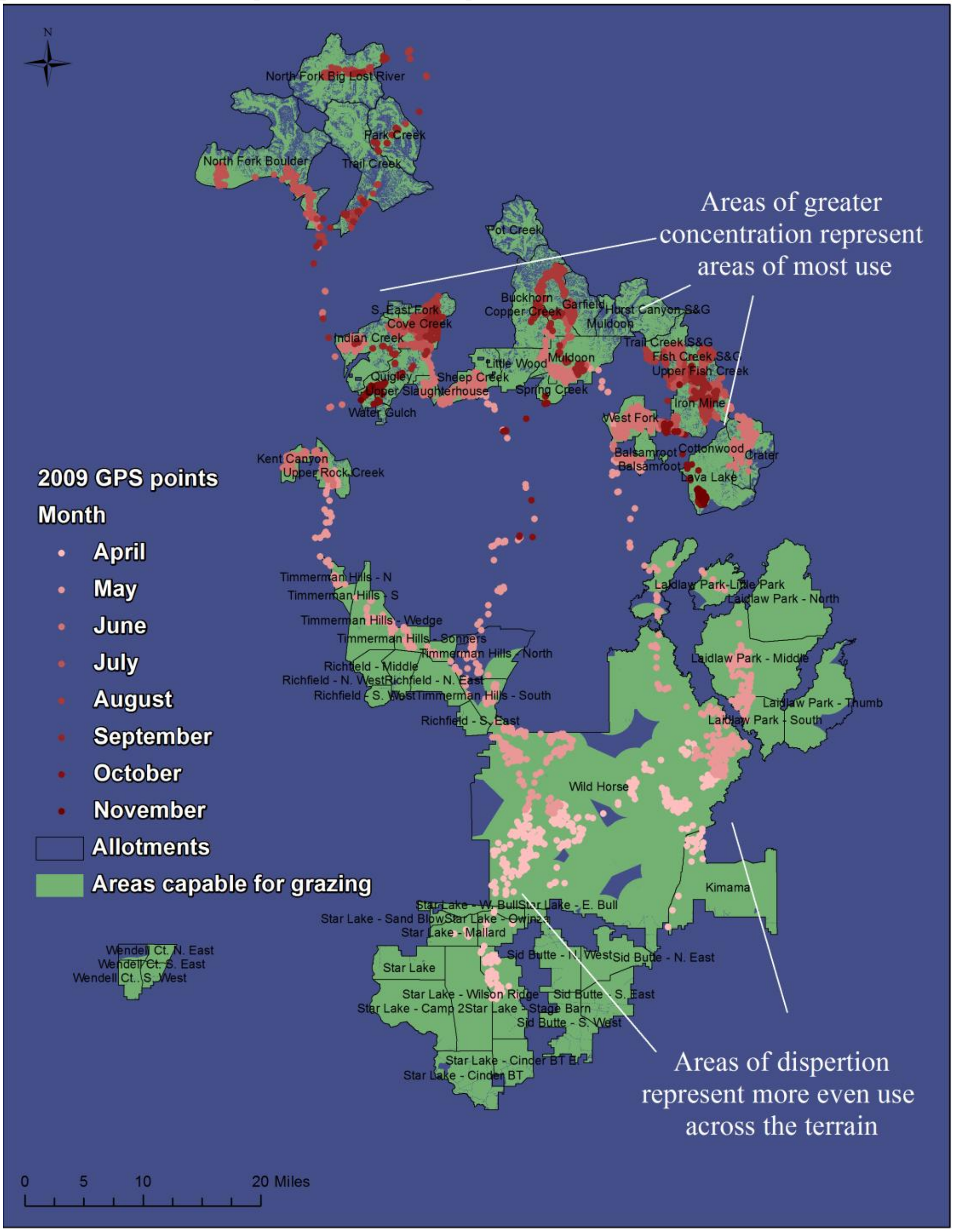
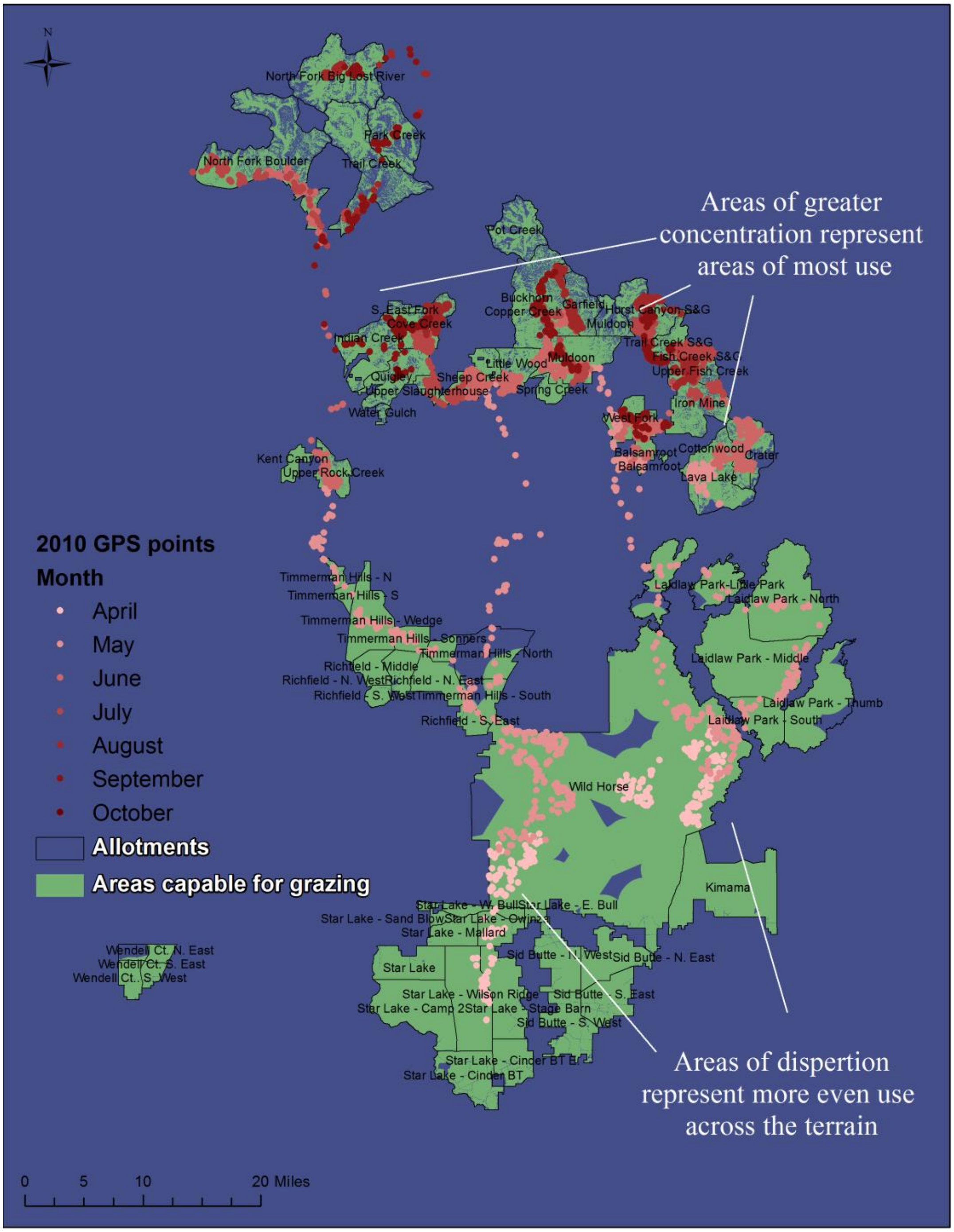


Figure 6.1, Continued



6.3 Discussion and Future work

The land management project is consistent with other studies conducted in determining terrain sheep are grazing, where vegetation and non-vegetation exists, as well as what additional sources can be added to open up unutilized areas, however it is not as accurate in comparison when defining areas suitable for sheep to be grazing. Compared with the study in the Awash River Basin (Bizuwerk *et al*, 2005) this project was compatible in identifying areas sheep are grazing as evidence by 94% in 2009 and 97% in 2010 of the GPS locations being within model outputs of capable areas. The project did not however, identify areas suitable for grazing by incorporating soil erosion levels, precipitation values, or an extended assessment of healthy vegetation levels where the Awash River Basin study did. As in the studies conducted in Virginia and North Carolina (Knight *et al*, 2006) as well as for land managers in the southwest (Marsett, 2006) this project's use of NDVI derived data provided maps of vegetative land cover type assisting land managers with representing where vegetation and non-vegetation exists. The land management project was comparable with the Natural Resources Conservation Service's study (Namkun & Stuth, 1997) in identifying non-grazing areas at high slope gradients and further then 2 miles distance from water; both offering an explanation for where additional water resources could be implemented opening up underutilized areas. However, the land management project did not identify areas of increased brush densities to determine treatment sites and in return provided a tool for locating areas of extended use for long periods of time.

Continuous assessment of how protocols are managed and implemented across the landscape is valuable to the sustainment of both the sheep and the ecosystem. The project was consistent with supporting sustainable ranching practices in identifying areas of extended use and generating more accurate acreage for use in capacity assessments. However, results show that influential factors such as the scale of data and scale in analysis, overall behavior of sheep, and additional grazing not documented in this project are introducing elements of uncertainty that should be addressed in future work as each plays a specific role in the final outcomes.

Scale is often an important factor to take into account when performing analysis with GIS and RS. This is due primarily to the way ground level objects are represented and related to one another within the computer. Therefore, when performing analysis across varying areas of a landscape it is crucial to do so in the same scale. In this study an appropriate use of scale was taken into account for both the time analysis (1:20,000 map to land unit ratio) performed within the GIS and when selecting and analyzing the NED (10 meter resolution) and NLCD (30 meter resolution) imagery.

When performing the time analysis and comparing different areas it is important to ensure the scale ratio is set to be identical. The scale ratio can influence the proximity of the GPS point data to one another, consequently impacting the overall representation of rate of travel, therefore all the small scale comparisons were set to the exact same ratio and all the large scale analysis is viewed and compared at the same ratio.

The scale in the RS imagery (referred to as resolution) impacts the overall analysis when inappropriately selected since it could introduce increased uncertainty in the delineation/extraction of raster to polygon elements used in the analysis. The ground resolution for all RS imagery used for this project offered a relatively accurate scale across the Lava Lake study area. Other RS imagery were available for the study area, however their courser resolution (250 meter ground resolution) was found to be inadequate compared to the 10 meter resolution that offered a more localized representation. To map the vegetation present in the study area better results could be achieved to this extent if higher resolution RS could be used. Higher RS imagery is expensive and unavailable therefore our selection was the best compromise between costs and reasonable achievable results.

The grazing behavior of sheep could affect the results of this analysis. The overall habits of sheep behavior are different in given temperature, certain times of the year and certain biological necessities. Temperature, relating to the seasons, is an influential factor contributing to a sheep's rate of travel because heat can increase stagnation where the cold can increase mobility. Seasons and temperature are closely related to one another in the study area located in south central Idaho. Summer and late autumn are traditionally higher in temperature, therefore sheep tend to graze in cooler areas (i.e. under shaded trees), and closer to water. Depending on the layout of the terrain this could lessen the overall area the sheep are grazing, thus slowing down their rate of travel.

Another pertinent behavior is mating, which plays a role by contributing to areas where sheep are located during different times of the year, and could also contribute to their rate of travel. Sheep mate in flat terrain so that the rams (male sheep) can perform without excessive exertion. Sheep could be navigating to flatter terrain at the time of mating. Therefore, the increase in travel rate could be due to mating behavior, temperature of the season, the ease of navigation across flatter terrain, or all three.

Where this project was specific to the study area it focused only on land management and grazing behavior of sheep by Lava Lake. However, it is worth noting that while Lava Lake utilizes the northern allotments throughout the majority of the year, other operators use the southern allotments more frequently. Most of the southern region allotments are shared with other operators who graze both sheep and cattle, therefore while Lava Lake does not graze their sheep excessively on the southern allotments these areas may still be at risk from over grazing by other operators, whose activity should also be included in future analysis for a more complete model.

Factors for Future work

There are certainly other pertinent factors when looking at other potential contributions to the analysis and the most relevant is vegetation. Vegetation is a direct link between the sheep and the landscape, therefore future analysis of factors contributing to vegetation such as plant species, biomass consumption, and precipitation will contribute to the overall determination of how sheep are interacting with the landscape. In return this would assist in specifying areas where sustainable ranching protocols are thriving and areas where they need further implementation.

Plant species may vary depending on season and location as well herbs, forbs, shrubs, and grasses grow differently during the spring, summer, and autumn months potentially due to how sheep choose to consume them throughout the grazing season. Elevation can also impact the types of plant species growing in lower terrain versus areas higher in elevation. Future work on this project could consider identifying types of plant species that characterize the vegetative land cover across the study area, and compare this to how the average sheep consumes them.

A main determining factor for grazing protocols is biomass consumption (i.e. the total amount of dry weight vegetation a sheep needs to sustain itself based on pounds). Varying types of plant species produce different types of biomass weight, so as to say areas where certain plants make up the majority of land cover will have a different biomass compared to areas with a different plant cover.

Precipitation has an impact on how vast and large a plant grows, thus contributing to a plant's total biomass. In addition to having less water sources, the southern allotments also receive less rainfall and snow than the northern ones. The more southern regions receive on average ten inches of precipitation a year, as you move further north it increases to around thirty inches a year (Brian Bean personal interview 3/5/2012) therefore it may be the case that the northern allotments have a higher overall biomass then the southern allotments.

Since both vegetation type and consequently biomass varies so greatly, between the southern and northern regions, further studies may show the northern allotments more adept at sustaining grazing for longer periods of time. A means to show what areas are truly at risk would also require incorporating vegetation type and biomass weight.

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